Seasonal Climate Forecasts in the U.S. – Past, Present, and Future

Klaus Wolter
NOAA-ESRL, Physical Science Division, and University of Colorado at Boulder, CIRES
klaus.wolter@noaa.gov

- *The 'Mother' of all Predictors: ENSO*
- *Other key Climate Prediction Center (CPC) forecast tools*
- *CPC operational skill*
- *Observed climate change: Not so fast*
- *'Lower-hanging fruit': 2yr Las Niñas, PDO-AMO, (N)AO…*

Earth System Research Laboratory
Physical Sciences Division
CIRES
Cooperative Institute for Research in Environmental Sciences
Western Water Assessment
NIDIS

Two relevant quotes:

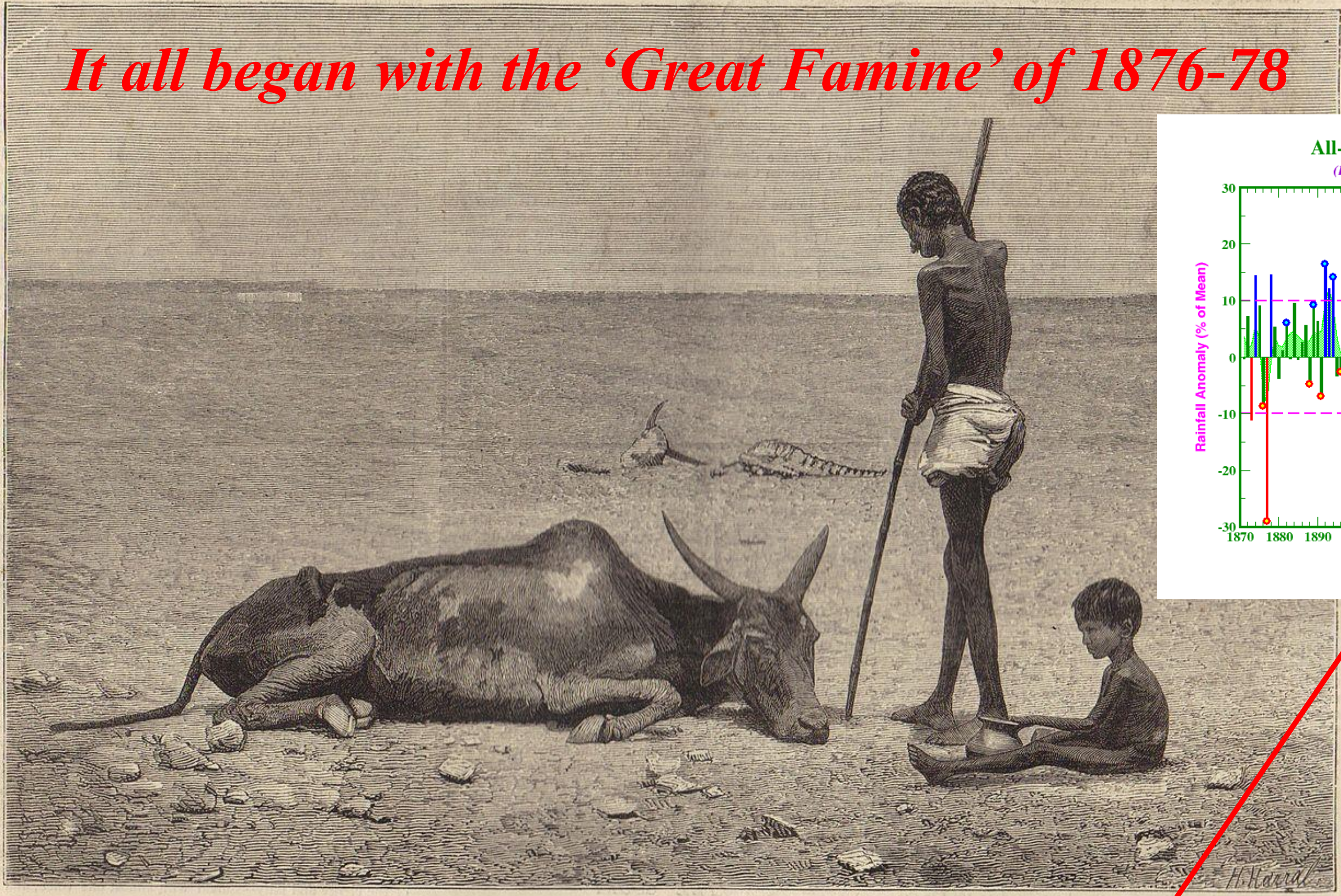
"It is a capital mistake to theorize before one has data. Insensibly one begins to twist facts to suit theories, instead of theories to suit facts."

Sir Arthur Conan Doyle, *Sherlock Holmes*

"Prediction is very difficult, especially if it's about the future."

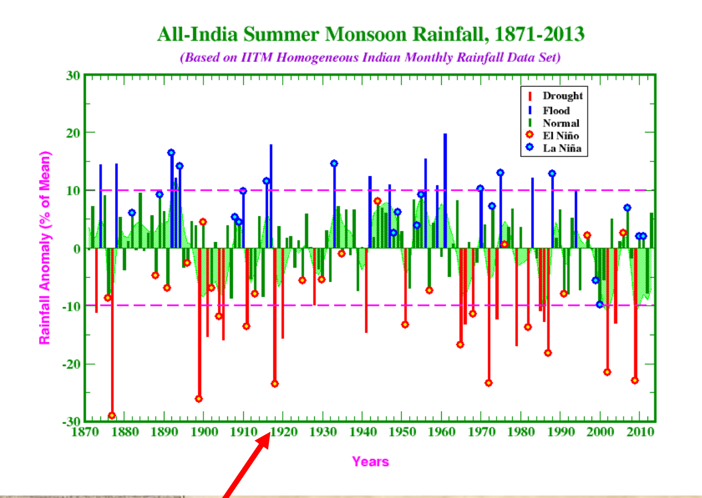
Niels Bohr, *Physicist*

It all began with the 'Great Famine' of 1876-78

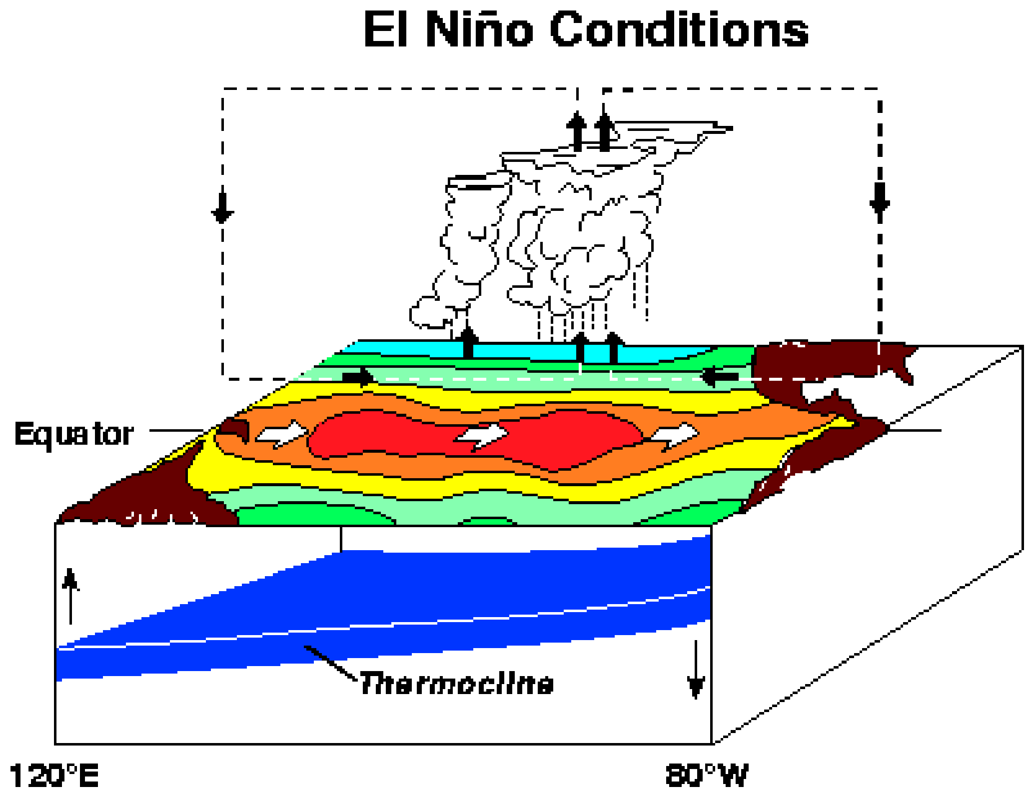


"THE LAST OF THE HERD"

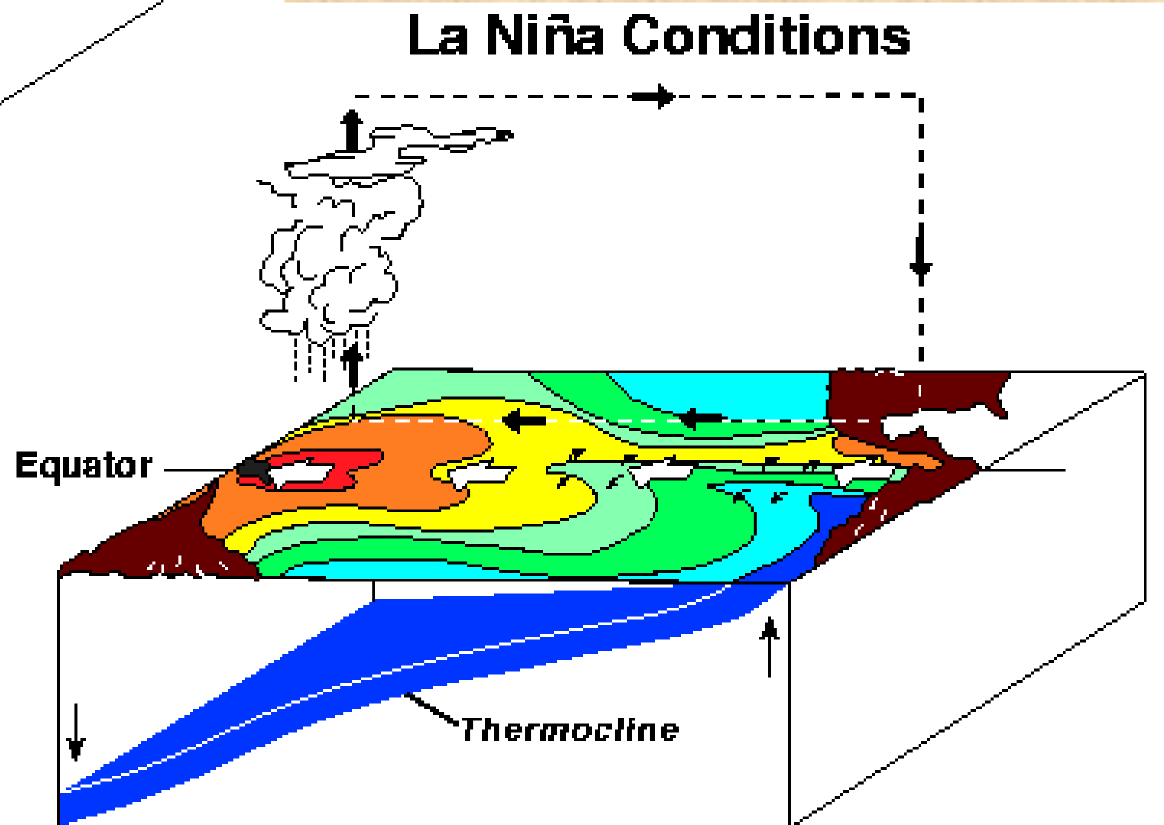
THE FAMINE IN INDIA — SCENES IN THE BELLARY DISTRICT, MADRAS PRESIDENCY



Perhaps as many as 5 million Indians starved to death (*http://en.wikipedia.org/wiki/Timeline_of_major_famines_in_India_during_British_rule#CITEREFFieldhouse1996*), one of the worst climate-related disasters on record, prompting one of the first concerted efforts to predict the summer monsoon (Blanford, 1884), in relation to Himalayan snowpack conditions. One of his successors, Sir Gilbert Walker (1910+) co-discovered links to the 'Southern Oscillation'.



Warm and cold phases of the ENSO (El Niño/ Southern Oscillation) cycle



Note changes in thermocline, surface currents, atmospheric convection, and resultant atmospheric circulation!

ENSO

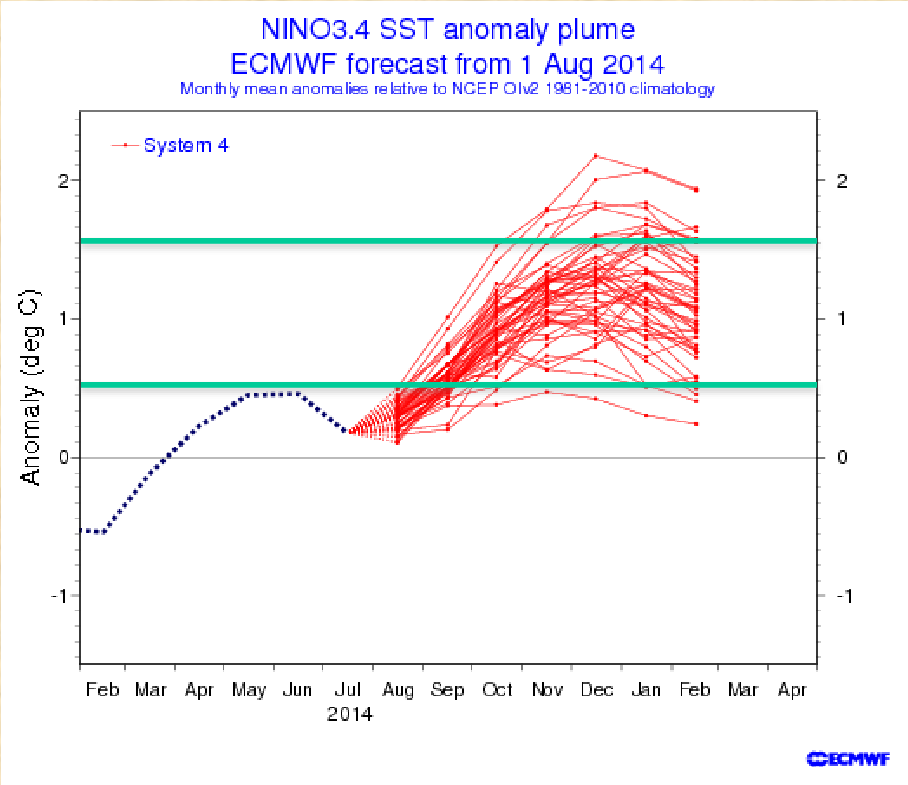
- **Discovered more than a century ago, J. Bjerknes (1966, 1969) is credited with coming up with physical explanations for this phenomenon. It took another two decades before U.S. climate forecasts took advantage of typical temperature and precipitation impacts during ENSO events (Ropelewski and Halpert, 1986, 1989).**

- **There are at least three ENSO indices in use these days: Niño 3.4 SST, Southern Oscillation Index ('SOI' based on SLP), and MEI (based on 6 different fields)**

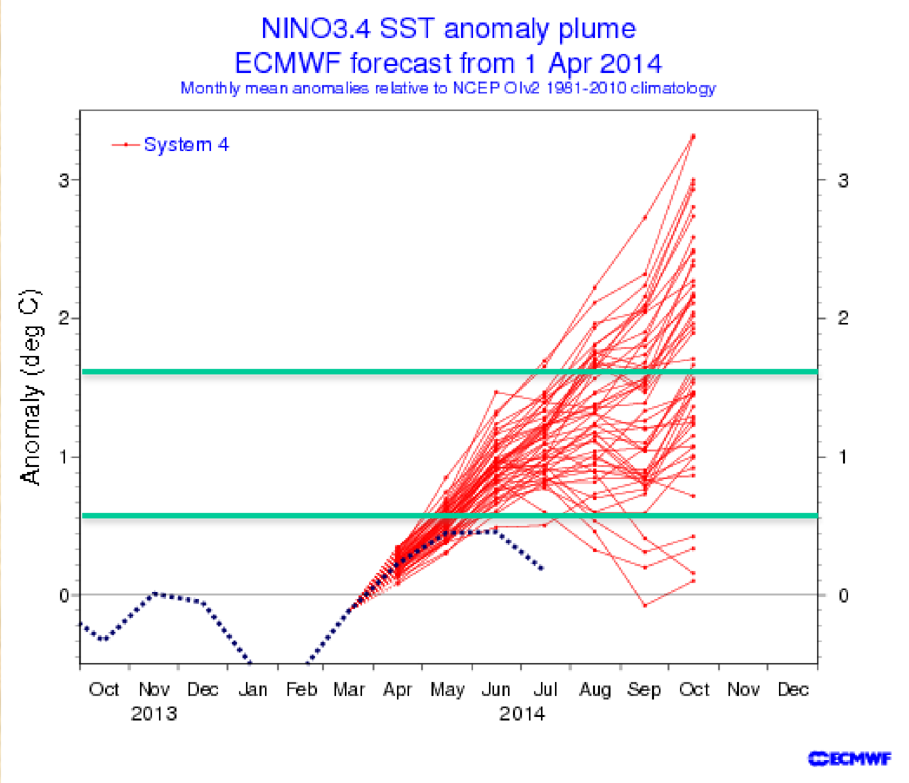
- **Choice of ENSO index influences which seasons one calls 'El Niño' or 'La Niña', especially in spring & summer (*current MEI is already in El Niño mode, while Niño 3.4 is still neutral*).**

- ***Most ENSO forecasts go after Niño 3.4, perhaps due to its benchmark nature for over a dozen coupled models predicting the same patch of sea surface temperatures (if a model cannot do that, how can we trust its 21st century runs?!). Compared to statistical forecast models, dynamical forecast skill has only recently become better (Barnston et al., 2012).***

Best coupled forecast model: ECMWF

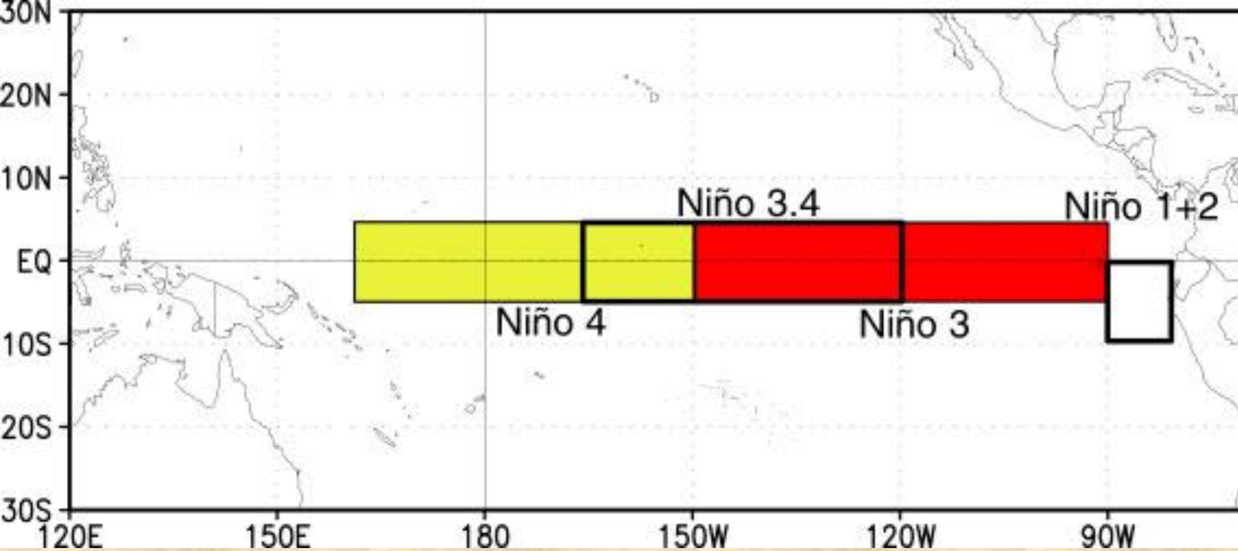


The ECMWF remains the 'gold' standard of coupled forecast models. The most recent one (left) shows that >90% of ensemble members favor El Niño, but of the <u>weak-to-moderate</u> kind. Just a few months ago (bottom), the model was more 'exuberant', with a good fraction of runs indicating strong (>1.5C) conditions. ***However, the observed SST (in blue) went outside the plume!***



http://www.ecmwf.int/products/forecasts/d/charts/seasonal/forecast/seasonal_range_forecast/nino_plumes_public_s4!3.4!plumes!

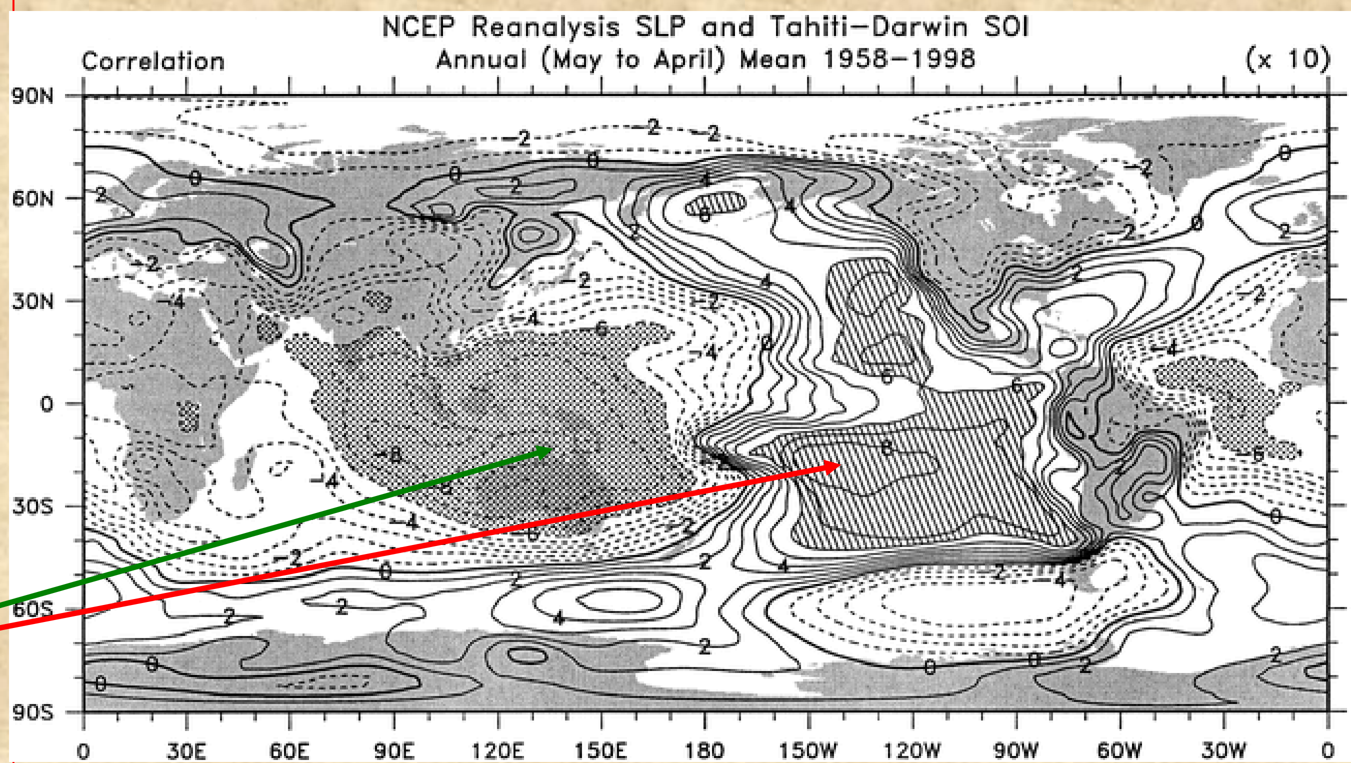
Perhaps, the range of 50 ensemble members gives us the 'known unknowns' for this forecast problem, while the recent excursions outside the forecast plume may be due to 'unknown unknowns', AKA 'reality bites'!



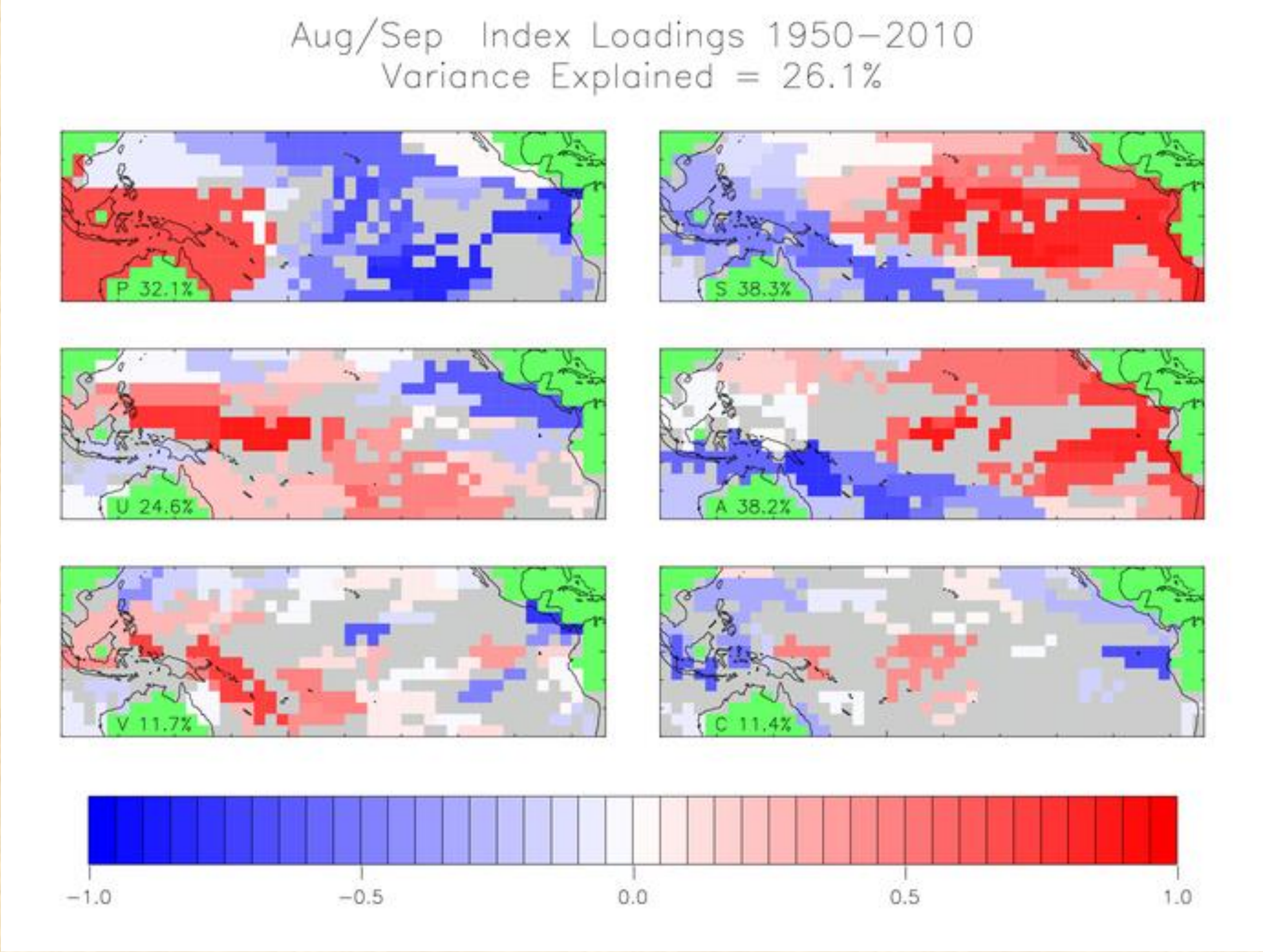
How should we monitor ENSO?

Trenberth&Caron, 2000

Niño SST indices were originally defined to capture tropical Pacific ship tracks (Rasmusson &Carpenter, 1982). ***Niño 3.4 was added as a slightly improved index by Barnston et al. (1997).*** **The Southern Oscillation Index (SOI) is defined as the normalized sea level pressure difference between Tahiti and Darwin.**



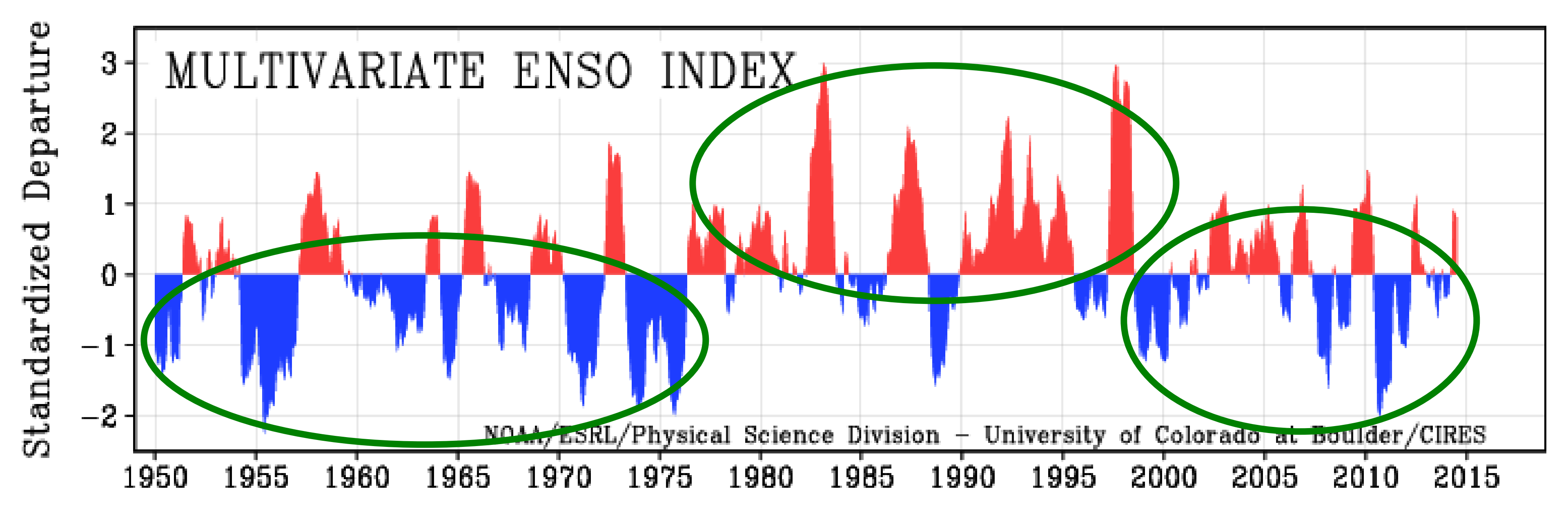
How should we monitor ENSO?



The Multivariate ENSO Index (MEI) was developed (Wolter and Timlin, 1993), and has been tracked on the web since 1997 to summarize major components of ENSO system in a single index, using the first unrotated Principal Component of six atmosphere-ocean variables: SLP, zonal&meridional surface winds, SST, air temperature, and cloudiness.

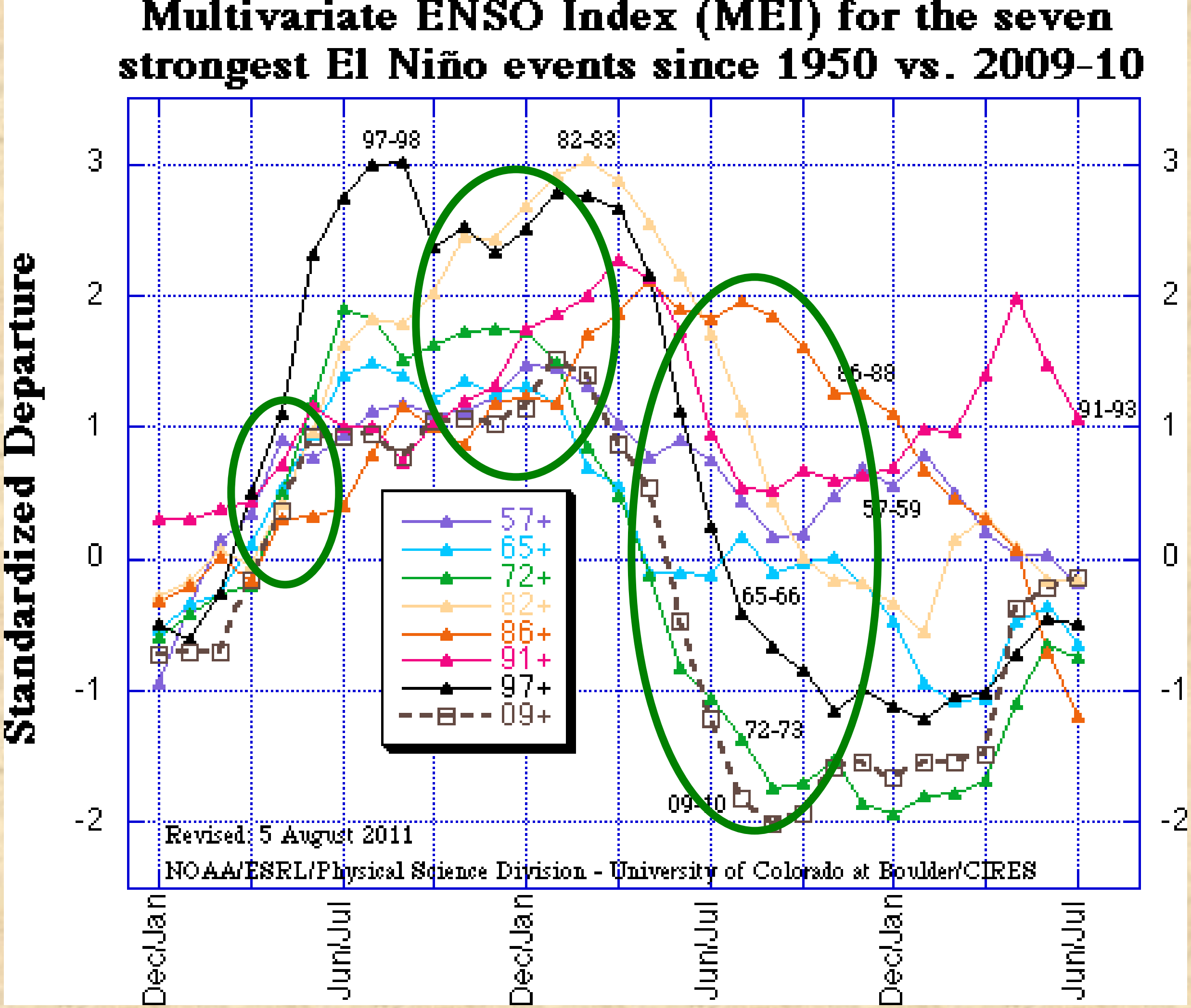
http://www.esrl.noaa.gov/psd/enso/MEI/

How should we monitor ENSO?



In order to allow for the combination of six atmosphere-ocean variables, each field is normalized to have standardized units. The resulting combined MEI time series has varied from about -2 sigma (standard deviations) to +3, while the long-term mean value is zero. After two decades of mostly El Niño conditions from the late 1970s through the late 1990s, the most recent 15 years have seen a return to more frequent La Niña events, not unlike the period from 1950-76.

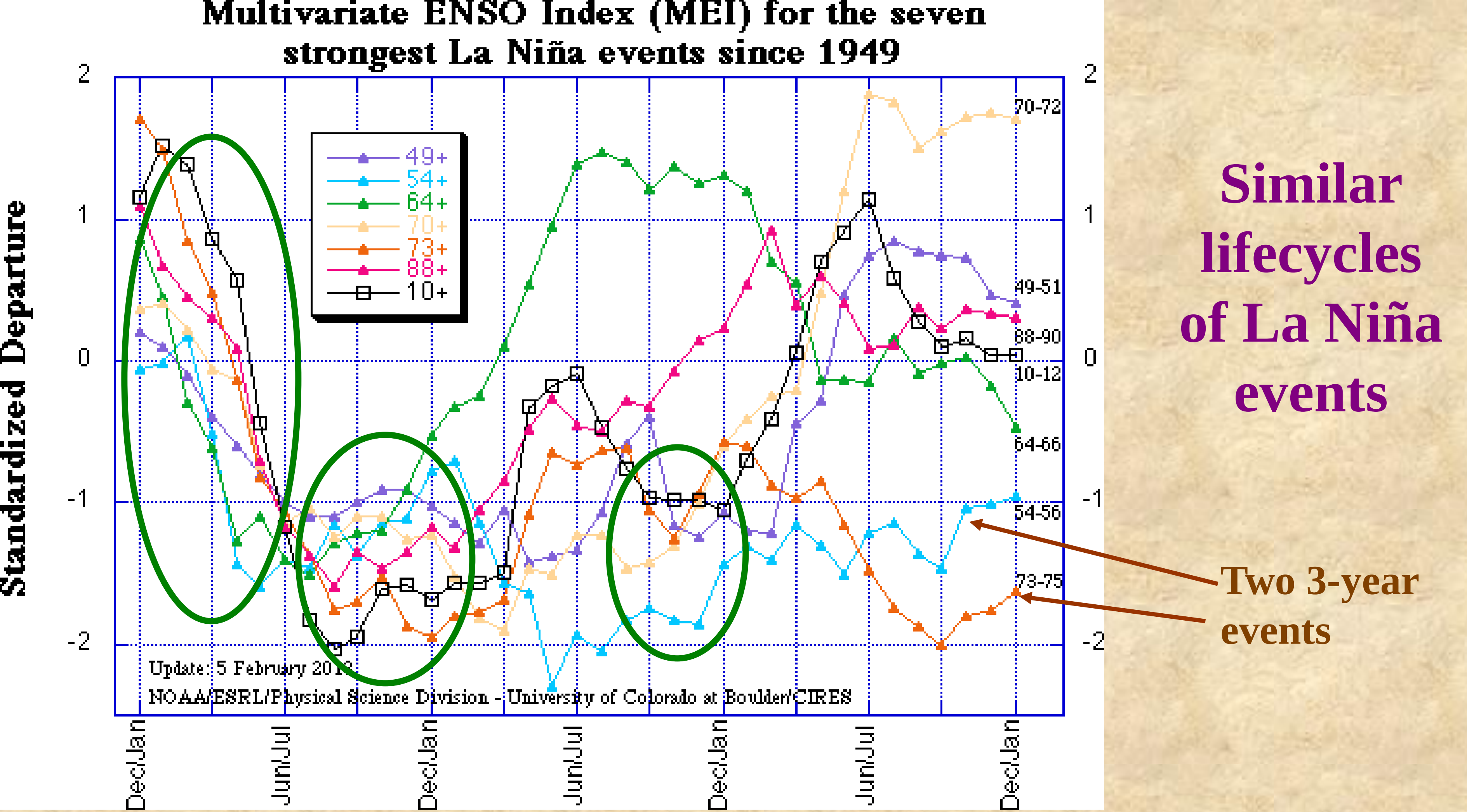
http://www.esrl.noaa.gov/psd/enso/MEI/



Similar lifecycles of El Niño events

Onset typically in boreal spring; all big ones persist through boreal winter; uncertain duration beyond that, although'Super-Los Niños tend to self-destruct ('82-83 and '97-98).

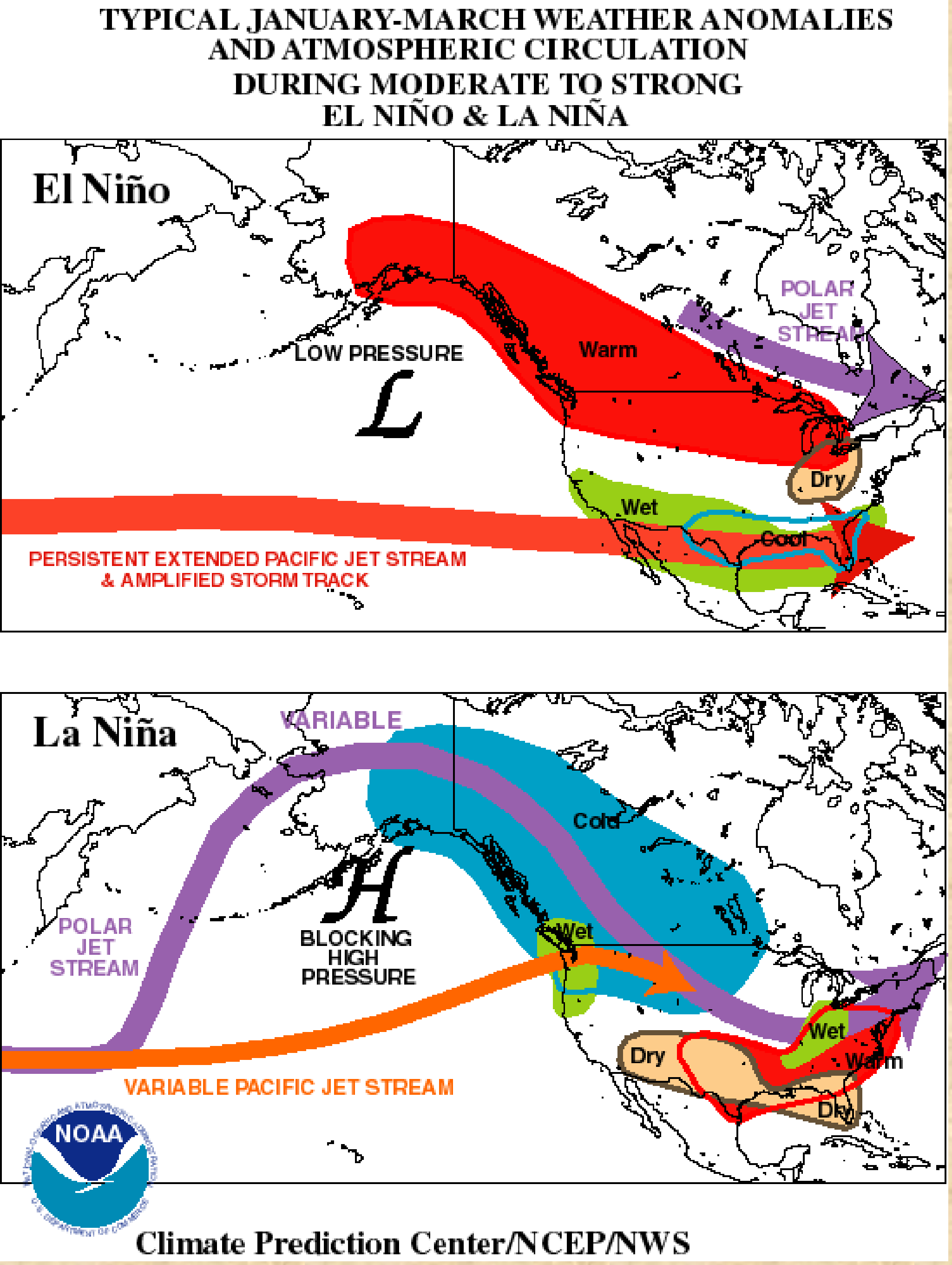
http://www.esrl.noaa.gov/psd/enso/MEI/



Similar lifecycles of La Niña events

Onset often in boreal spring; all big ones persist through boreal winter; in fact, the biggest Las Niñas tend to last the to last the longest – up to about three years.

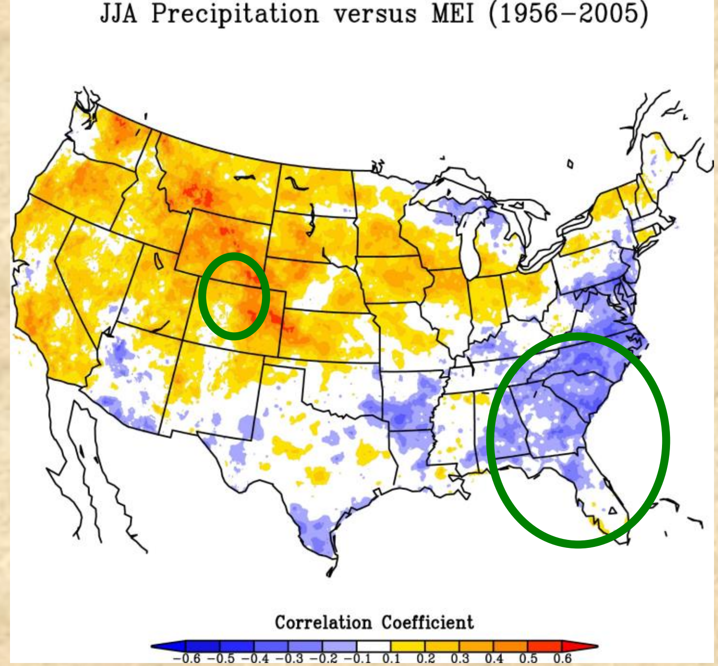
http://www.esrl.noaa.gov/psd/enso/MEI/



ENSO Impacts on North American Climate

El Niño is often associated with 'split flow' regimes over Western U.S., with an enhanced subtropical storm track across Southern U.S.

La Niña is often associated with a weakened subtropical jet stream, and tends to give us (MT, WY, CO) more frequent wind storms, and more snow in northern and central Rockies.

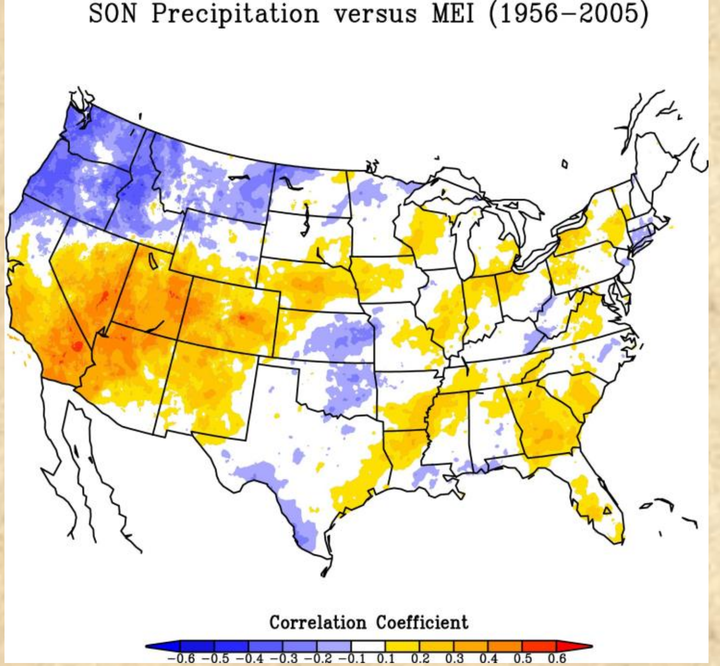


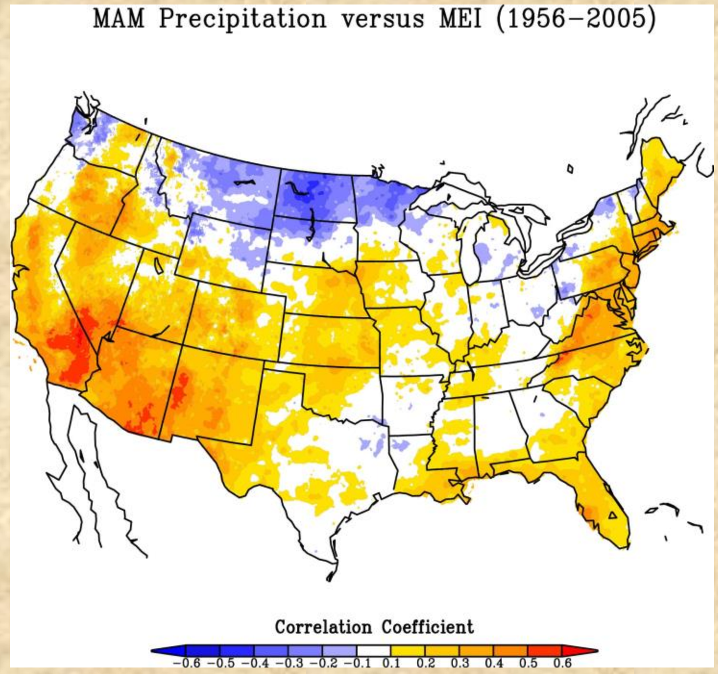
Seasonal cycle ENSO impacts

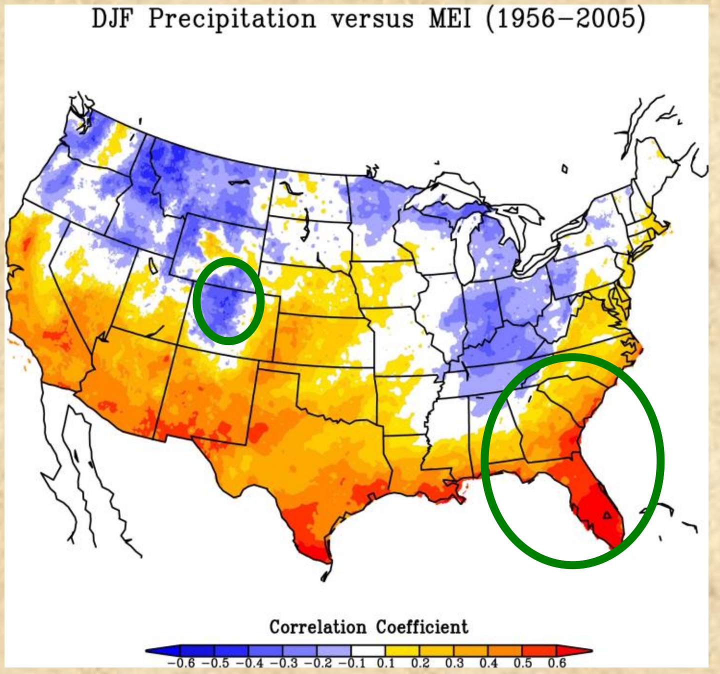
Upper Colorado basin tends to be wet with El Niño conditions for much of the year, except for the winter season, *especially at higher elevations.*

Southeastern U.S. shows negative correlations during the summer, while winter in particular shows the inverse.

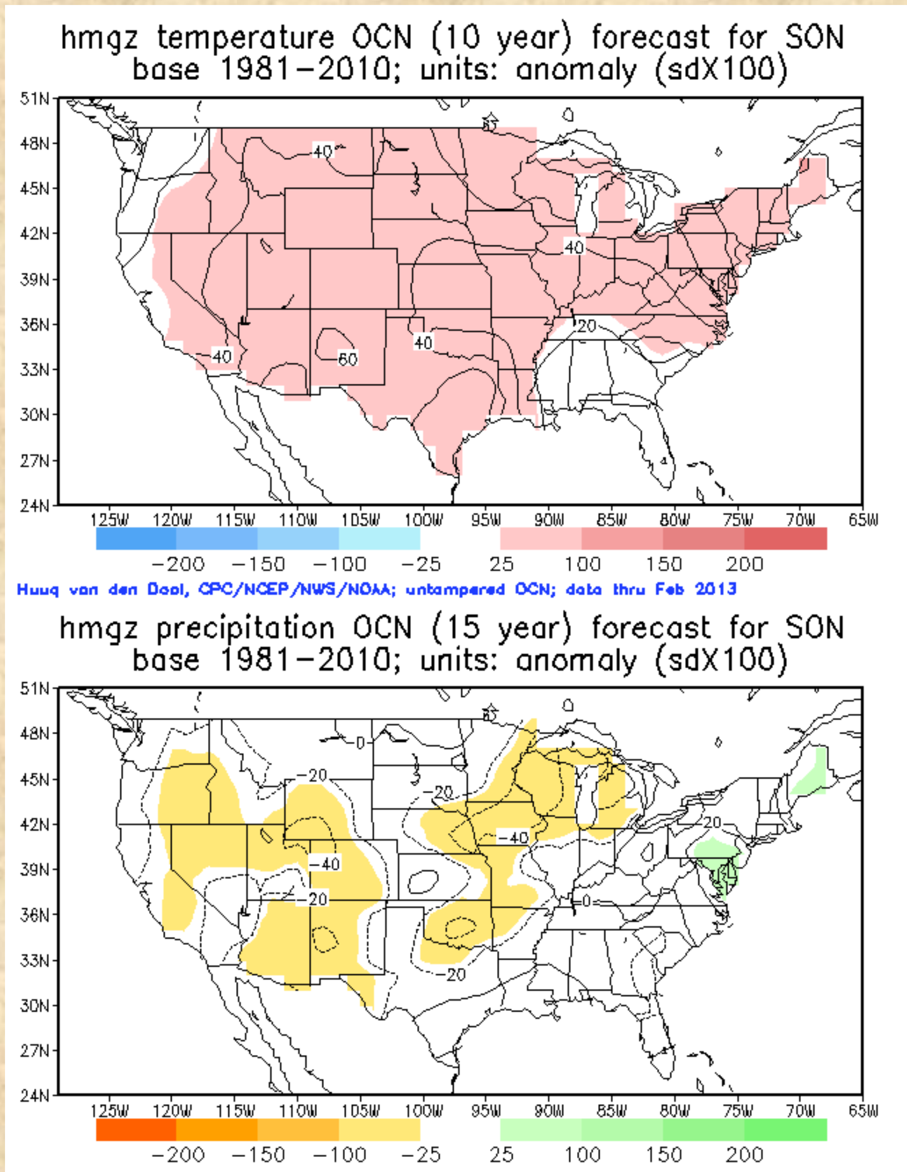
There are not too many parts of the U.S. that have same sign anomalies with the







Important CPC tools besides ENSO composites

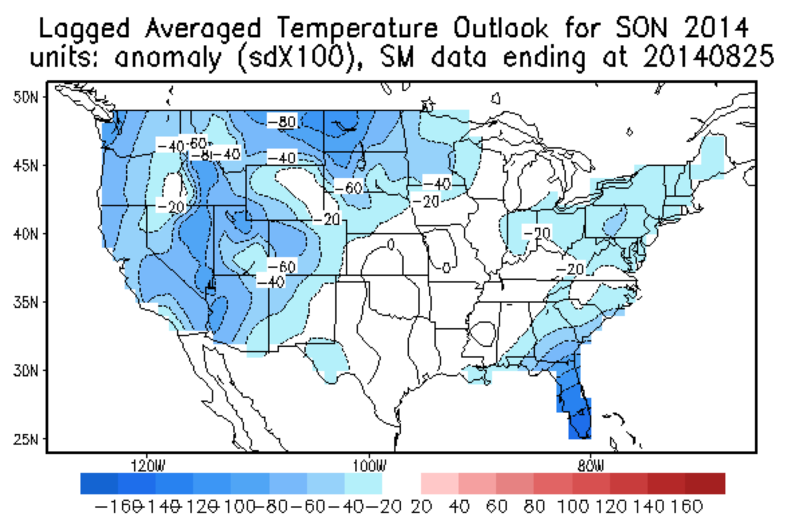


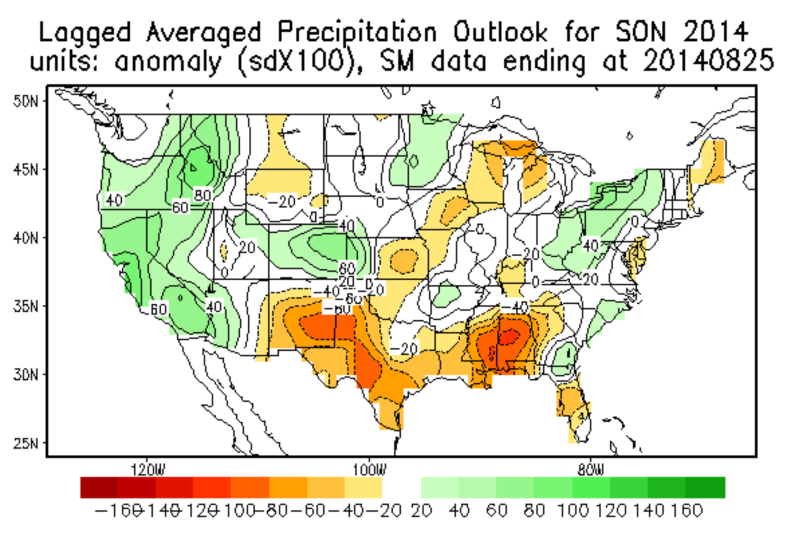
‘OCN’

<u>Optimum climate normals</u> **take advantage of the fact that there is decadal variability (or trends) that has some skill in parts of the country, more for temperature (warming!) than for precipitation. The discovery of this tool enabled CPC to extend forecast out to one year or more since 1995. For the upcoming fall season, a drying trend covers much of the U.S.**

http://www.cpc.ncep.noaa.gov/products/predictions/90day/tools/briefing/index.pri.html

Important CPC tools besides ENSO composites

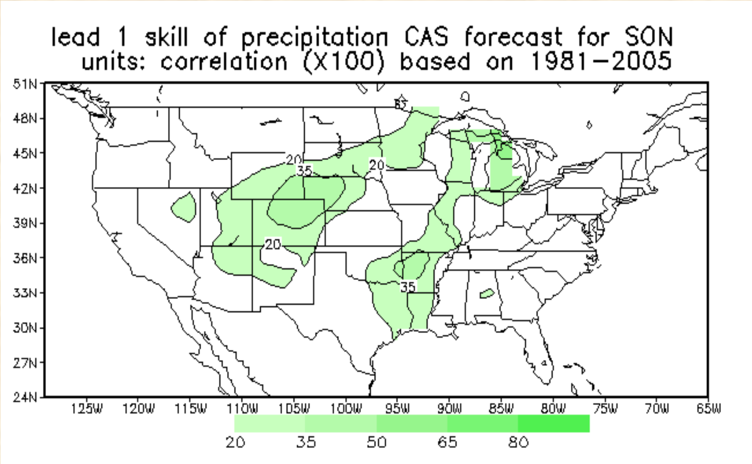




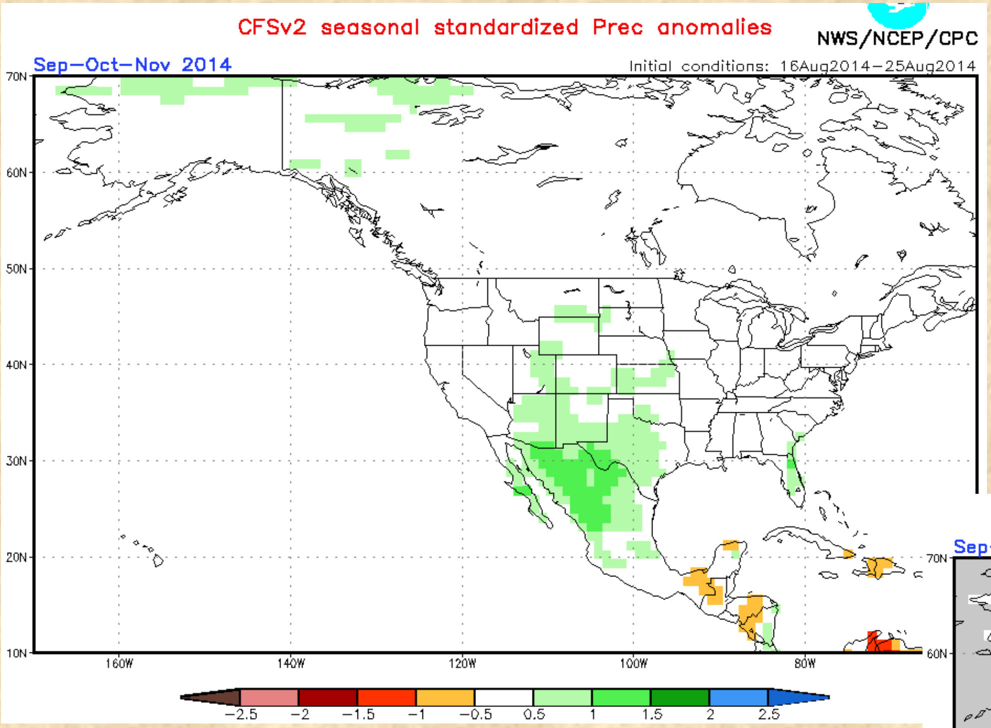
Soil Moisture Analogue

During the growing season, soil moisture carries information that can be used to shape seasonal forecasts. This tool compares the current soil moisture distribution around the country and compares it to historically similar (and dissimilar) patterns. For this particular season, precipitation forecast skill is best right around here. Latest forecast bucks trend in Southwest (OCN), but is consistent with El Niño.

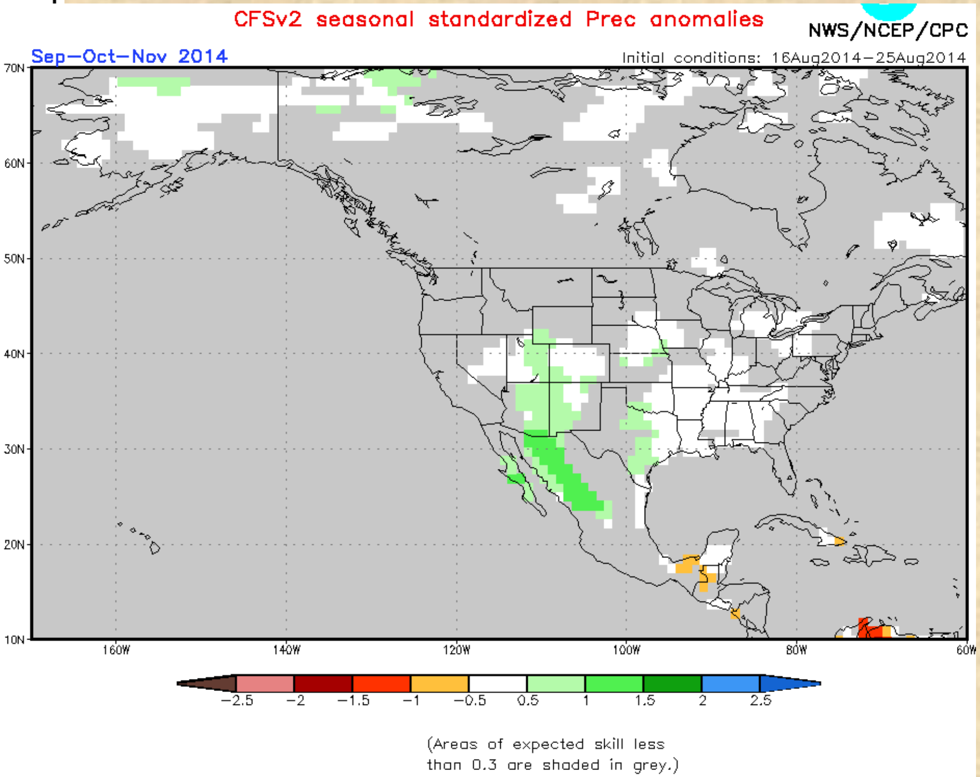
http://www.cpc.ncep.noaa.gov/products/predictions/90day/tools/briefing/index.pri.html



Important CPC tools besides ENSO composites

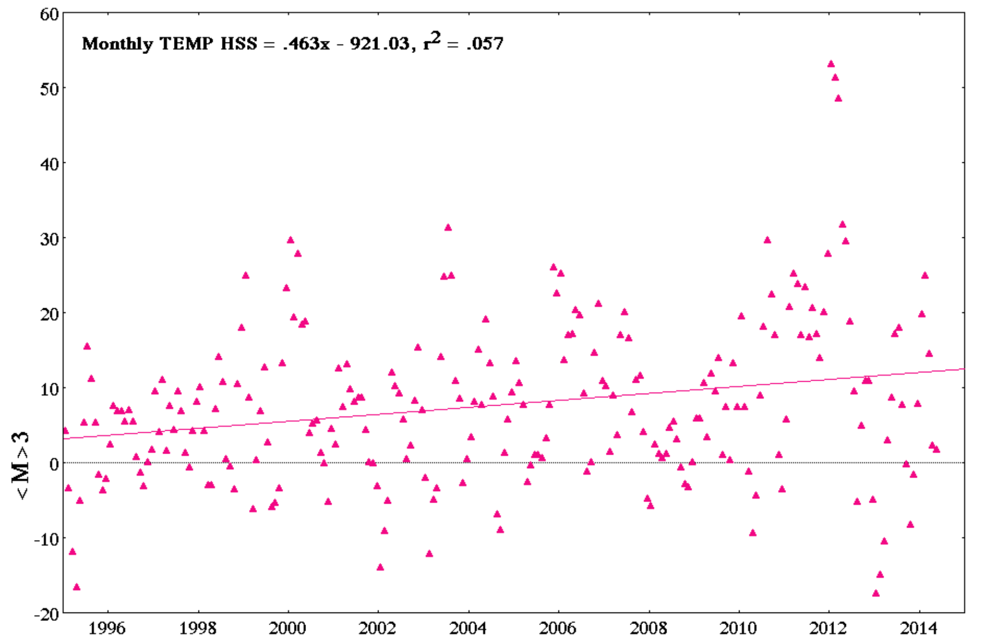


Coupled Forecast System (Version 2)



Not as exuberant as just a month ago, the latest fall forecast by CFS2 keeps it moist from Mexico into High Plains, not unlike the constructed analogue tool both in terms of moisture in vicinity and skill levels. This tool has gained ground in usage over last decade.

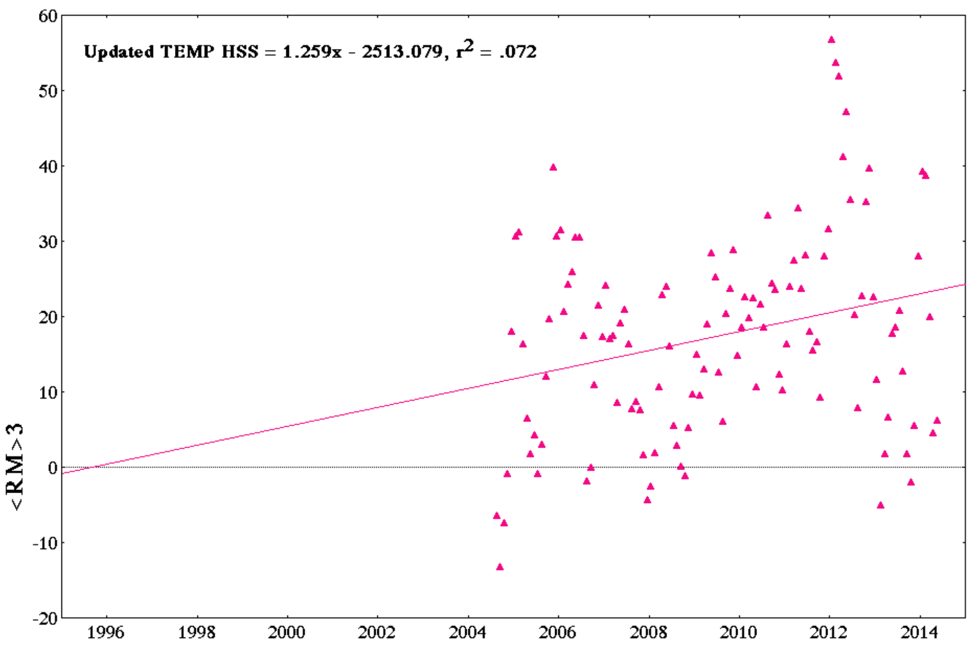
CPC Forecast Skill – Monthly Temperatures



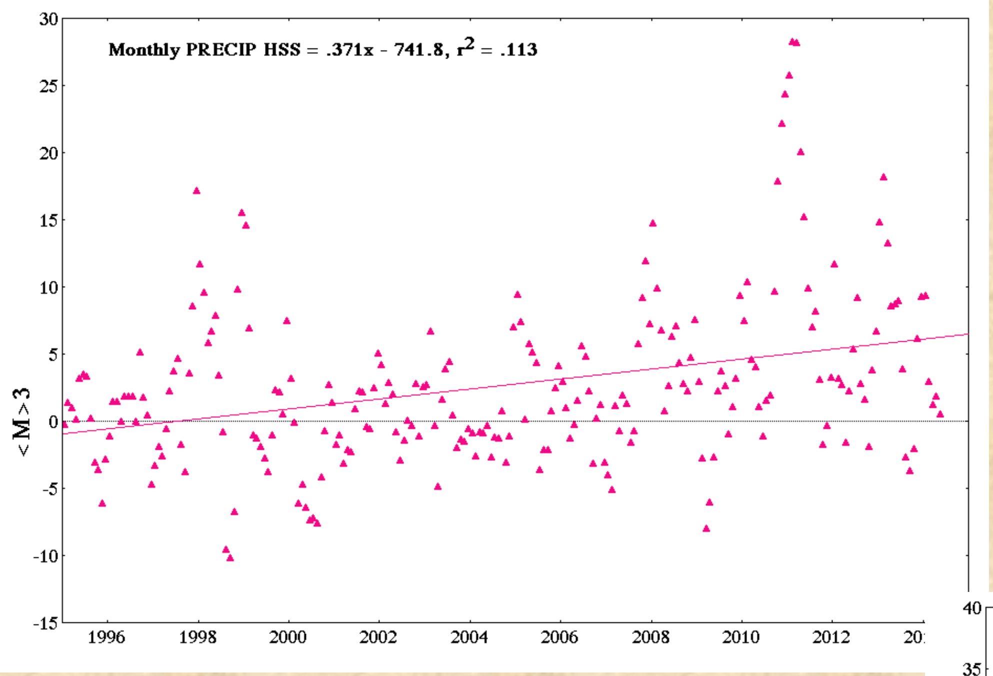
http://www.cpc.ncep.noaa.gov/products/predictions/long_range/tools/briefing/mon_veri.grid.php

CPC operational temperature forecast skill (Heidke Skill scores) for monthly forecasts (top) and updated monthly forecasts (right). Skill has improved over time, especially for updated forecasts.

Note peak skill around March 2012 (Dole et al., 2014), but negative skill as recently as 2013!



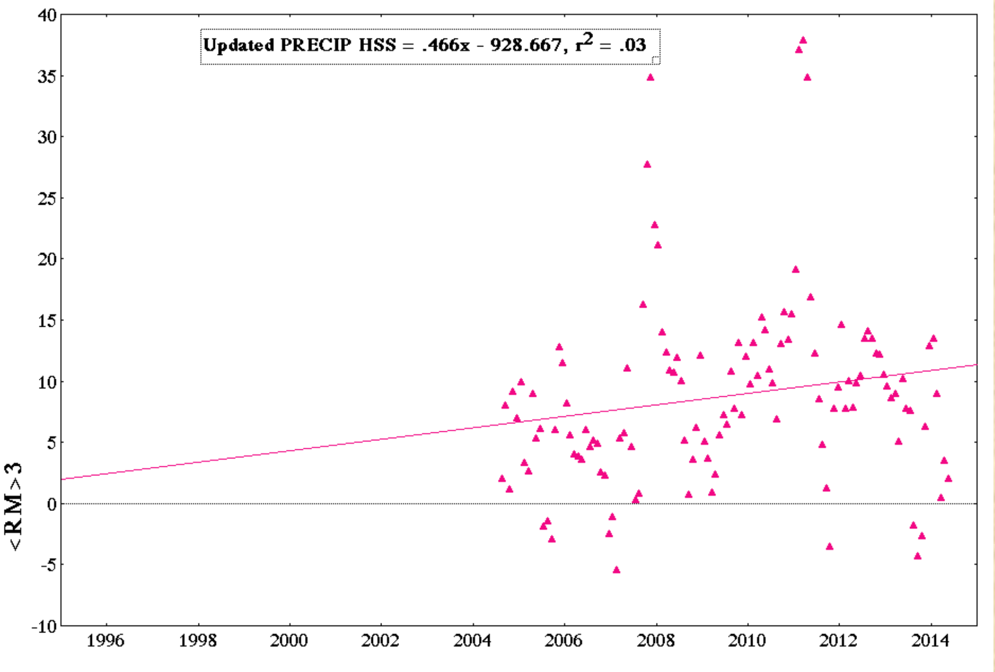
CPC Forecast Skill – Monthly Precipitation



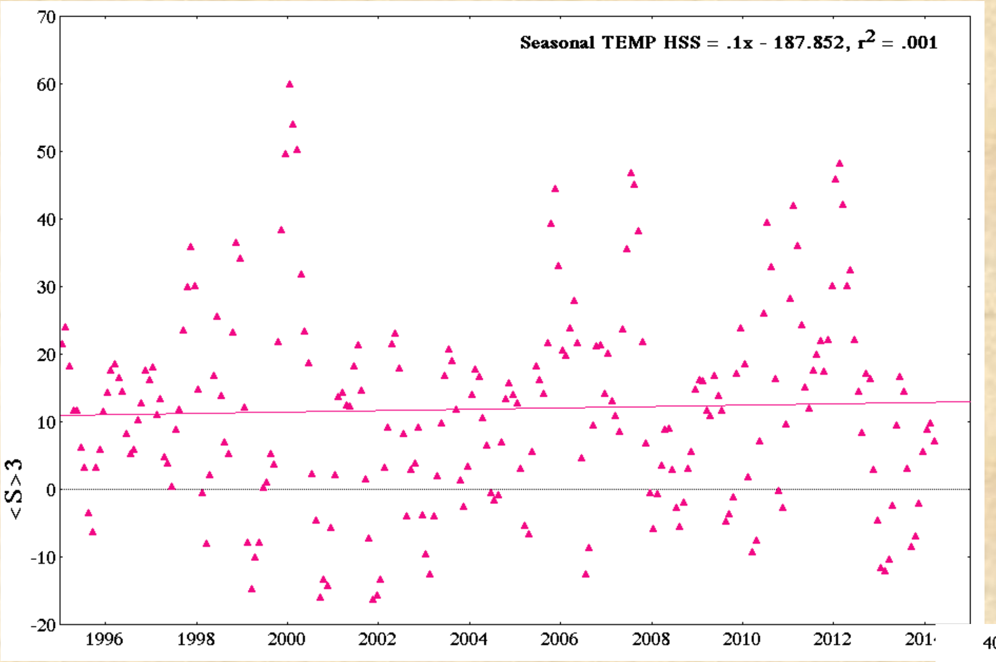
http://www.cpc.ncep.noaa.gov/products/predictions/long_range/tools/briefing/mon_veri.grid.php

CPC operational precipitation forecast skill (Heidke Skill scores) for monthly forecasts (top) and updated monthly forecasts (right).

Skill has improved over time (peak in spring of 2011), but less so than for temperatures.



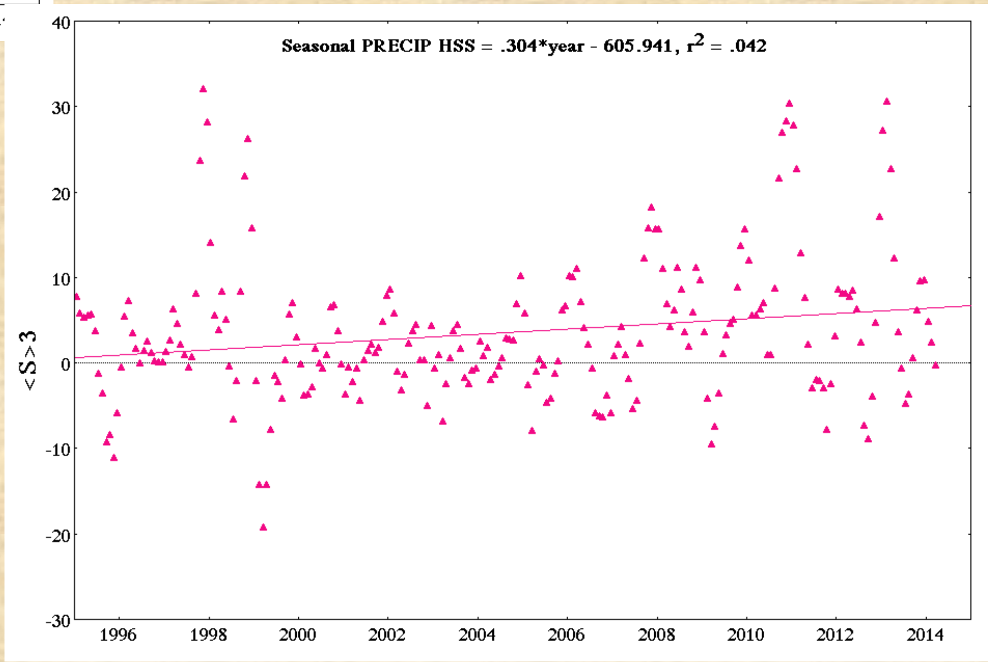
CPC Forecast Skill – Seasonal temperatures & precipitation



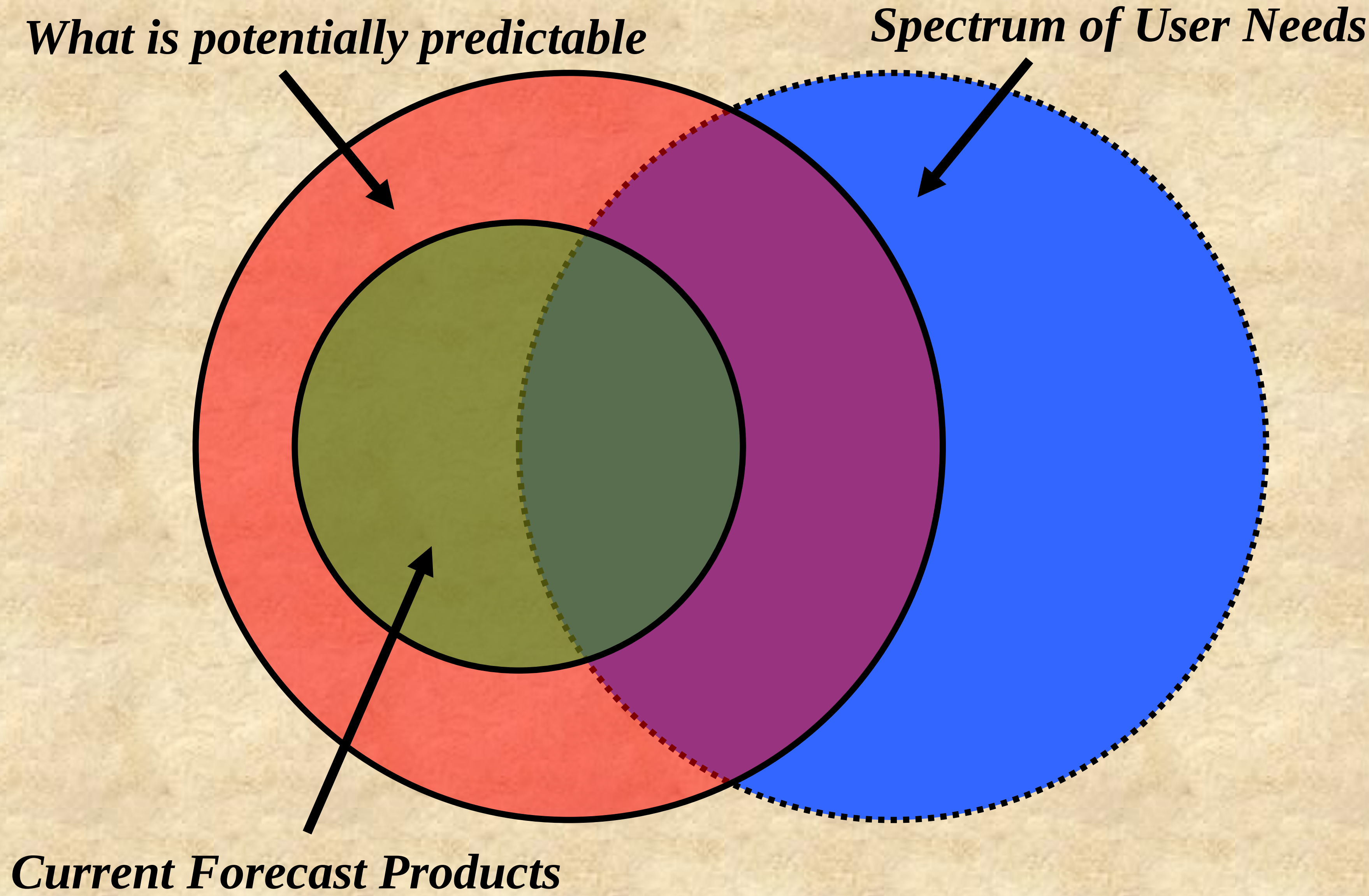
http://www.cpc.ncep.noaa.gov/products/predictions/long_range/tools/briefing/seas_veri.grid.php

CPC operational precipitation forecast skill (Heidke Skill scores) for <u>seasonal</u> temperature (top) and precipitation forecasts (right).

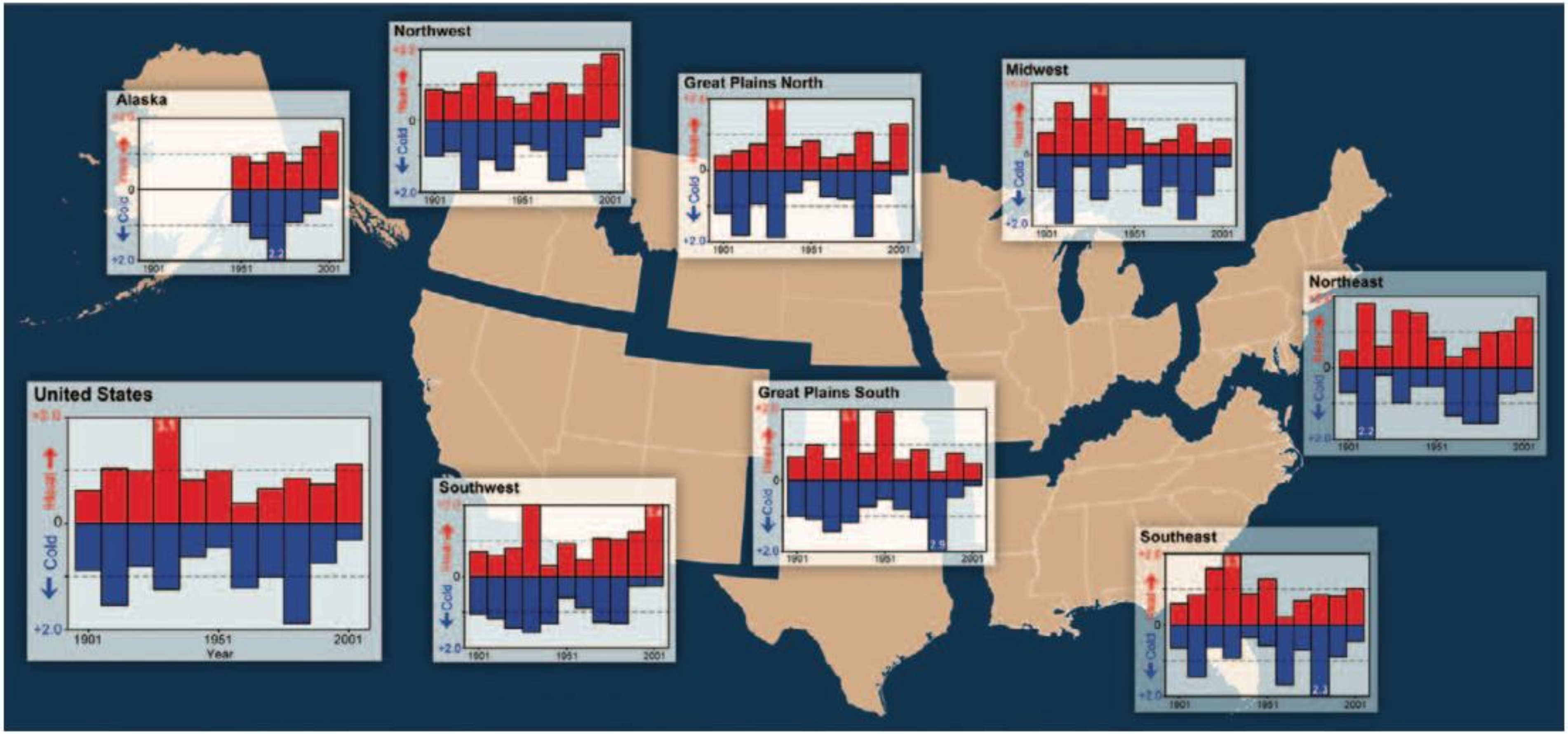
Surprisingly, temperature skill has flat-lined overall, with some growth in skill for precipitation, but still plagued by runs of poor skill.



Relationships among current products, potentially predictable, and needed climate information (Dole, 2001)



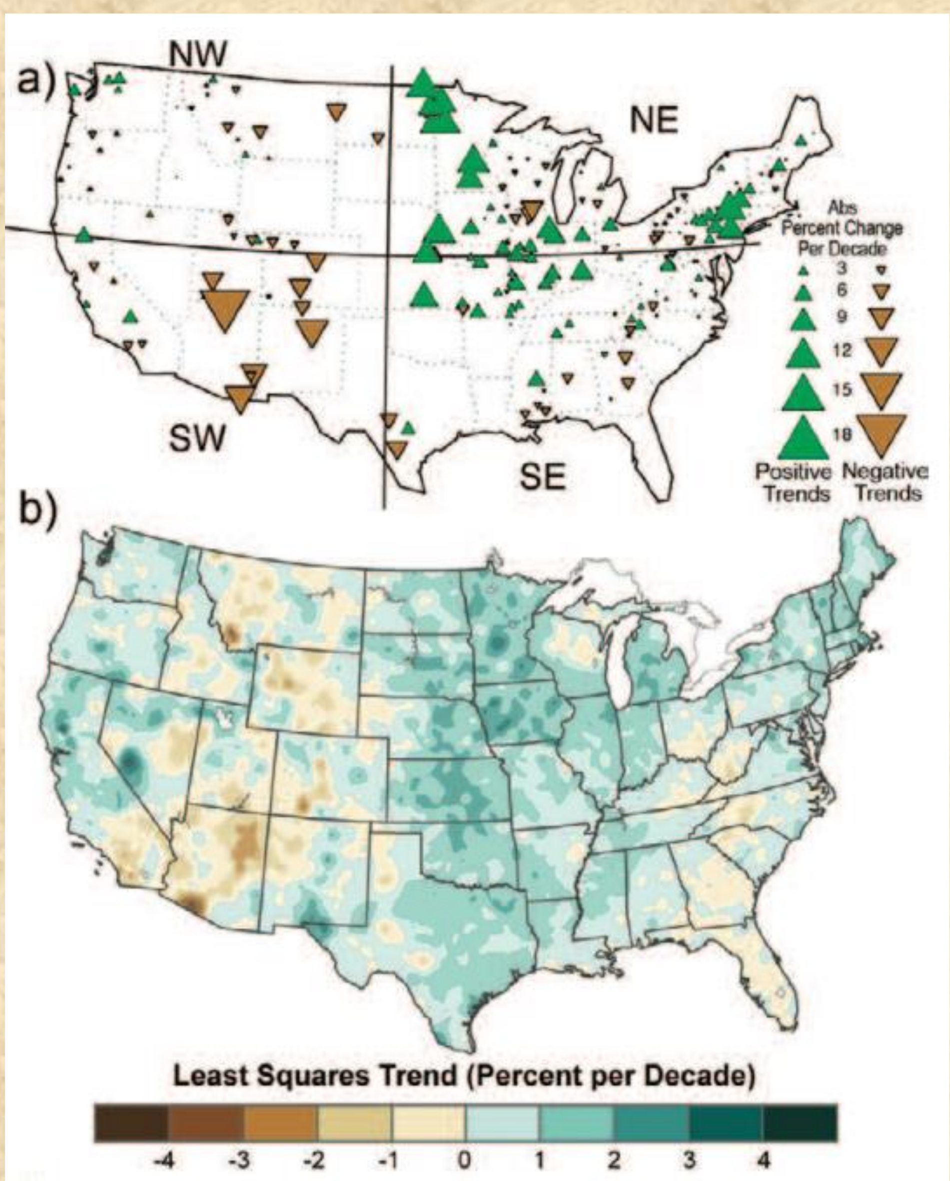
Trends in heat vs. cold waves ('sanity check')



'Pesky' 1930s had more heat waves than last decade, while the 1980s featured the most frequent cold waves!

Peterson et al., 2013

Trends in floods & annual precip ('sanity check')

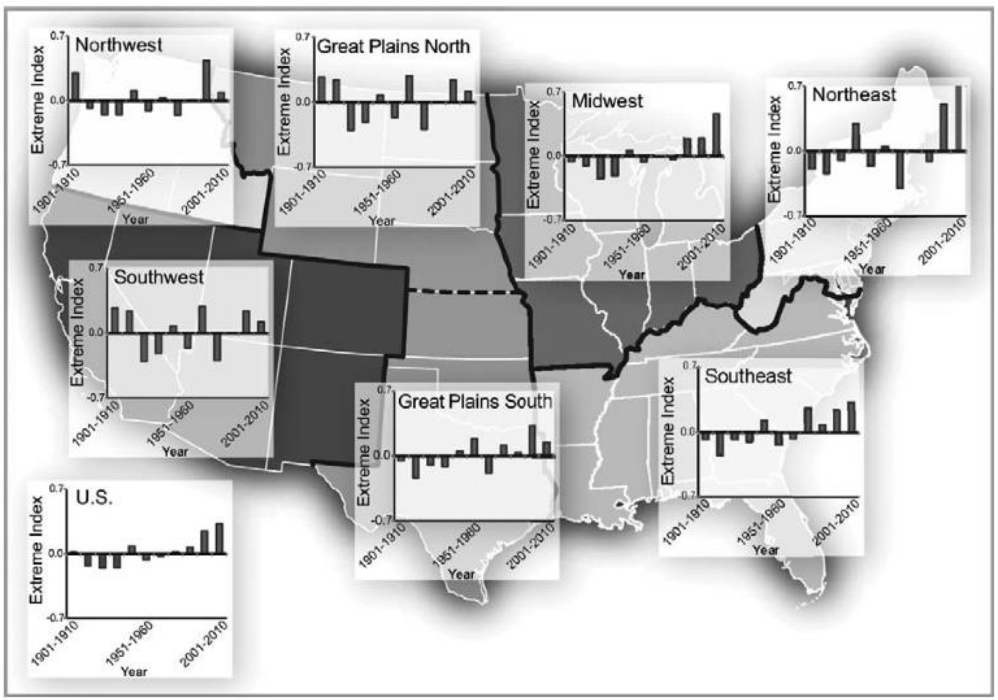


Over the last century, peak runoff cases ('floods') have trended upwards in northeastern U.S., and downward in southwestern U.S.

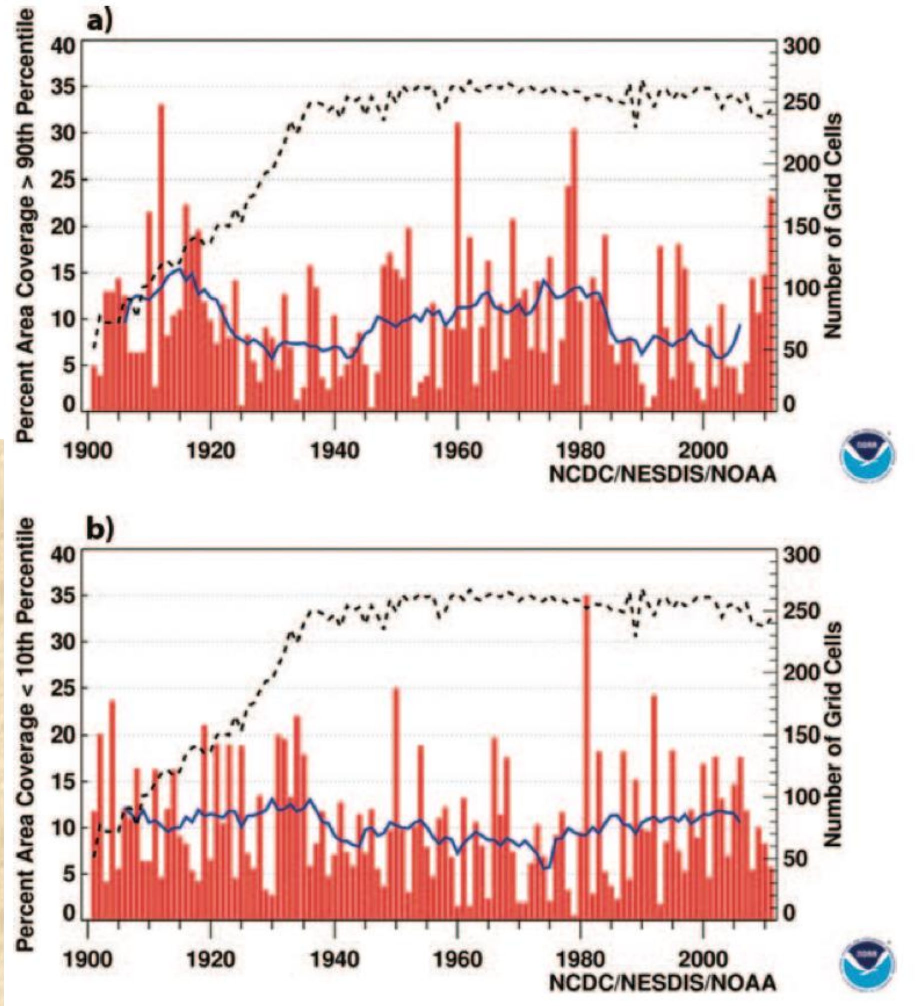
This more or less matches trends in annual precipitation.

Peterson et al., 2013

Trends in daily extreme rainfall & snow seasons

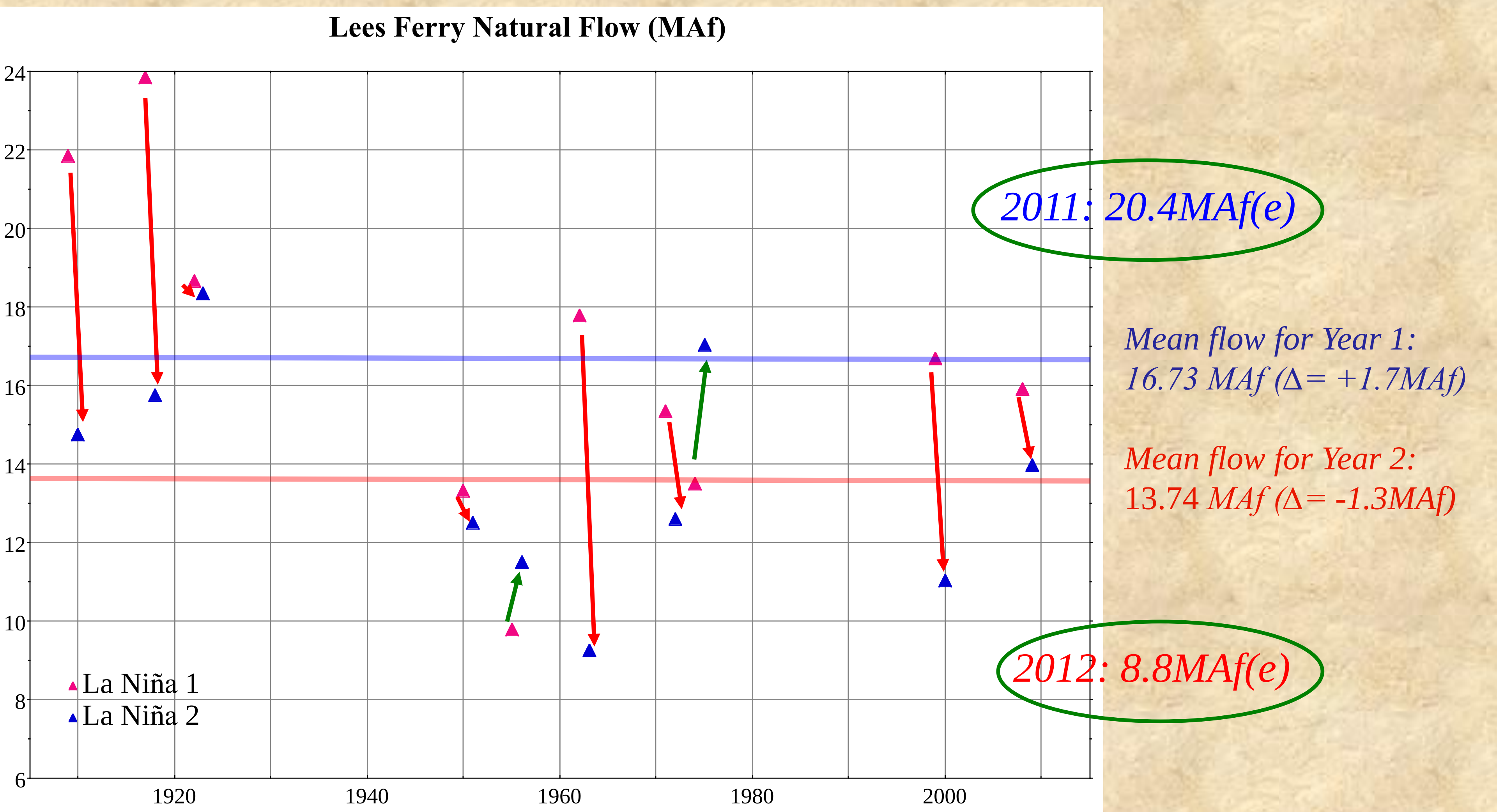


Kunkel et al., 2013



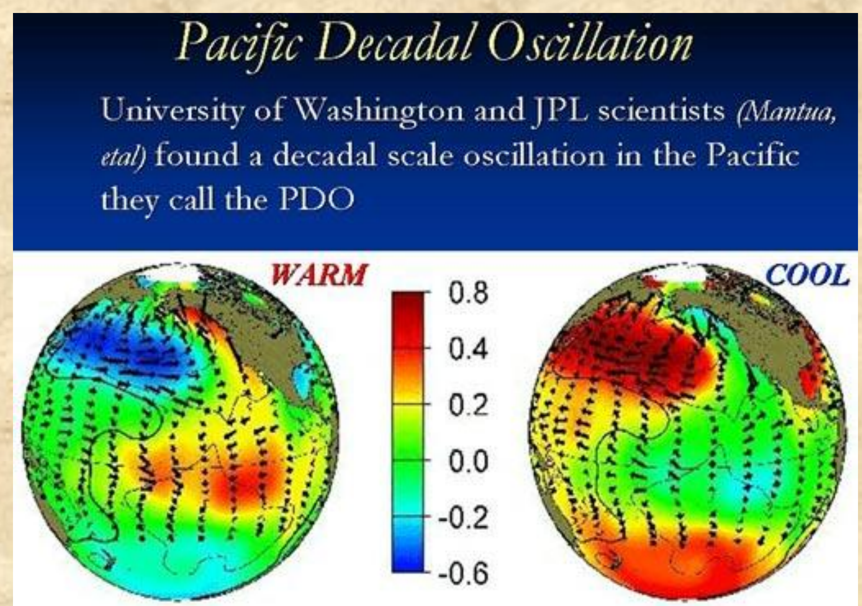
Rainfall extremes have been trending upwards over the eastern U.S. (top), while both low- and high-end snowfall seasons have flatlined over the last century (right).

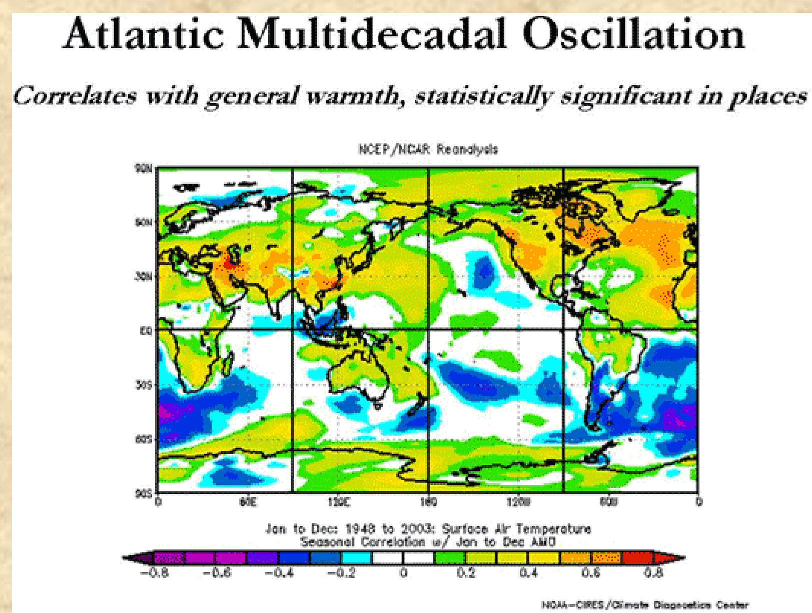
Two-year Las Niñas: Predicting impacts into Year 2

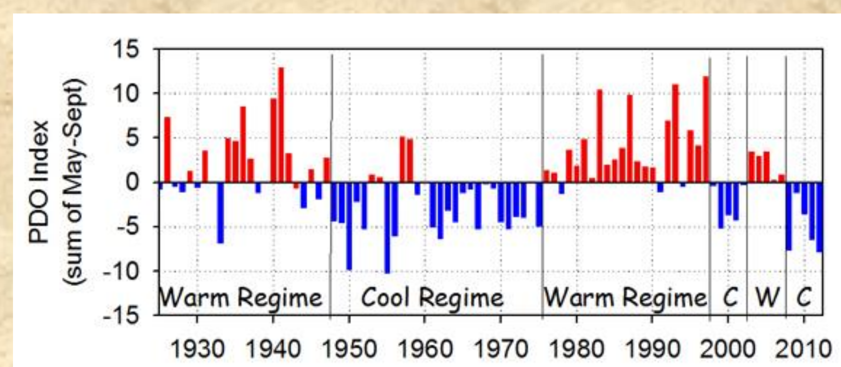


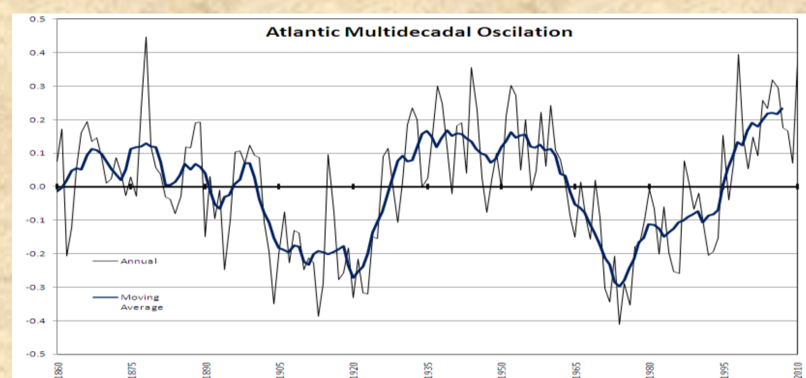
In 2-yr La Niña events, Colorado River runoff is often lower in 2nd year than in 1st year (8 of 10 cases), especially after a high 1st runoff year. The runoff seasons 2011 and 2012 confirmed this nicely (after seeing how big La Niña got by August 2010, I alerted water managers to this).

PDO and AMO



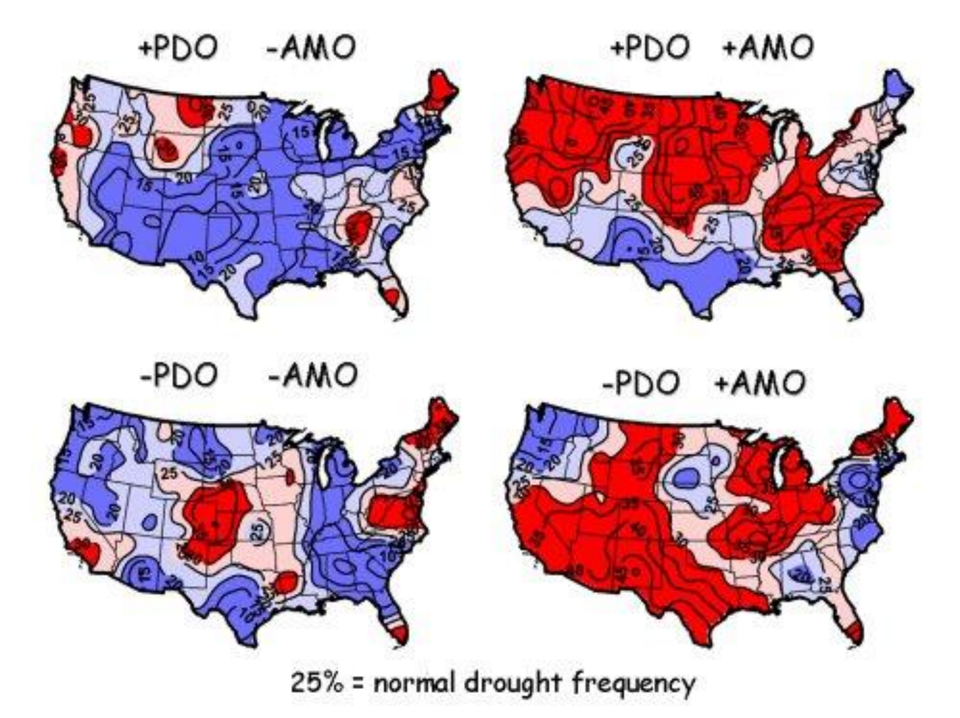


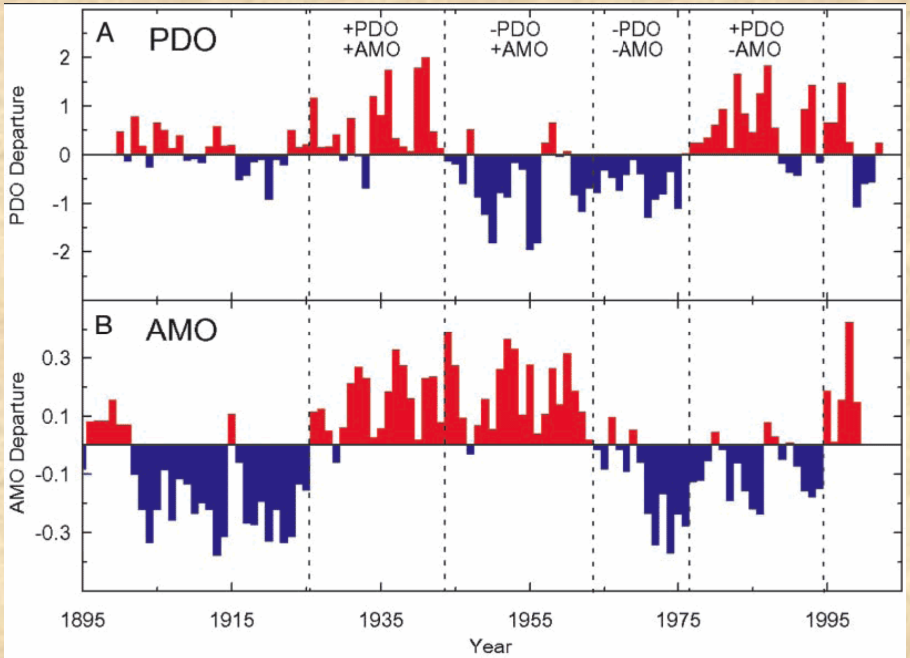




PDO and AMO describe main behavior of North Pacific (left) and North Atlantic (right) SST variations, mostly outside the tropics.

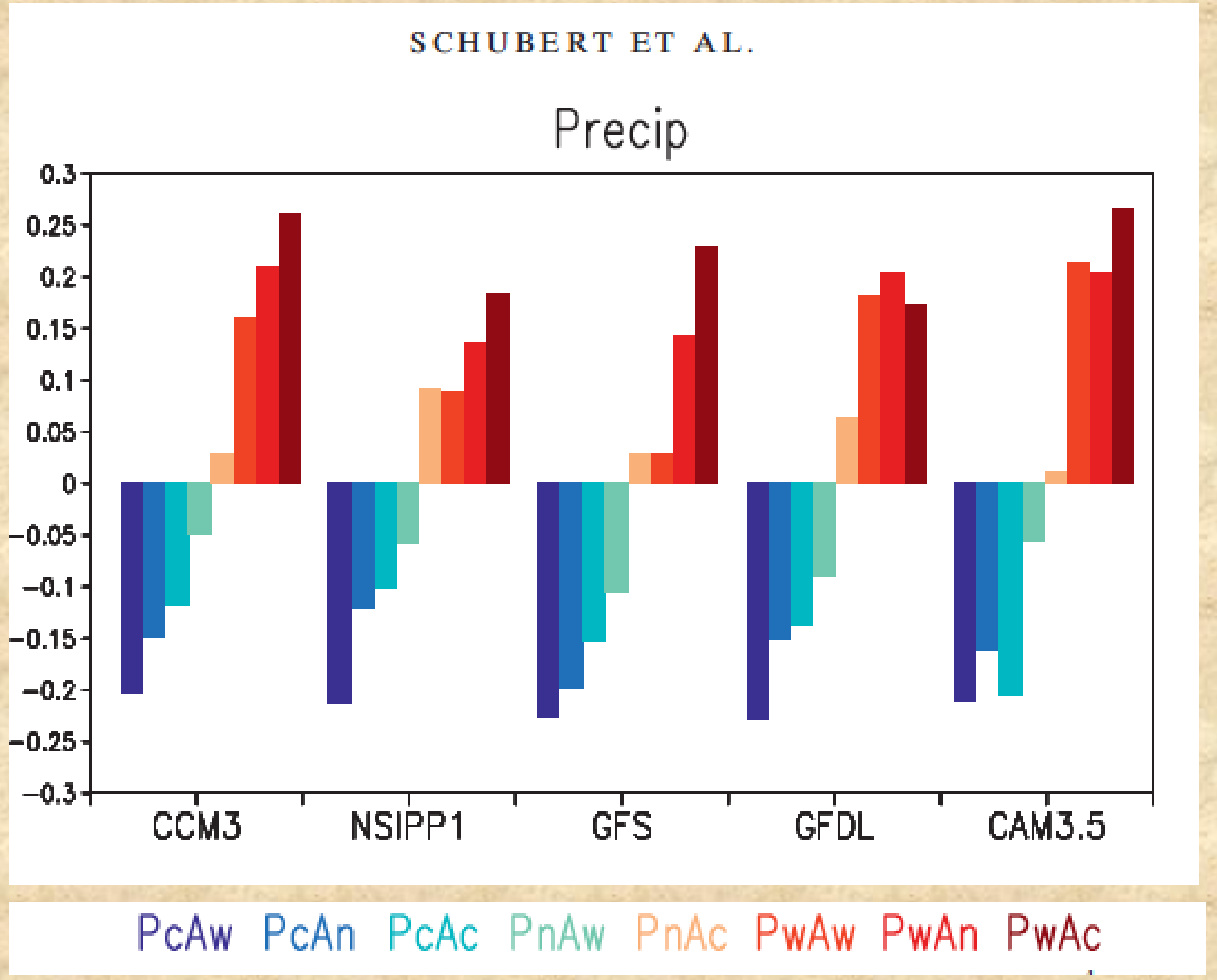
PDO and AMO





McCabe et al. (PNAS, 2004) main point was that a positive AMO (right side of left figure) leads to drought conditions over most of the U.S., shifted to the north during the positive PDO (a la 1930s), and shifted to the south during negative PDO (a la 1950s as well as since about 2000). A few years later, Schubert et al (2009) repdocued this overall finding with a comprehensive modeling study (next slide).

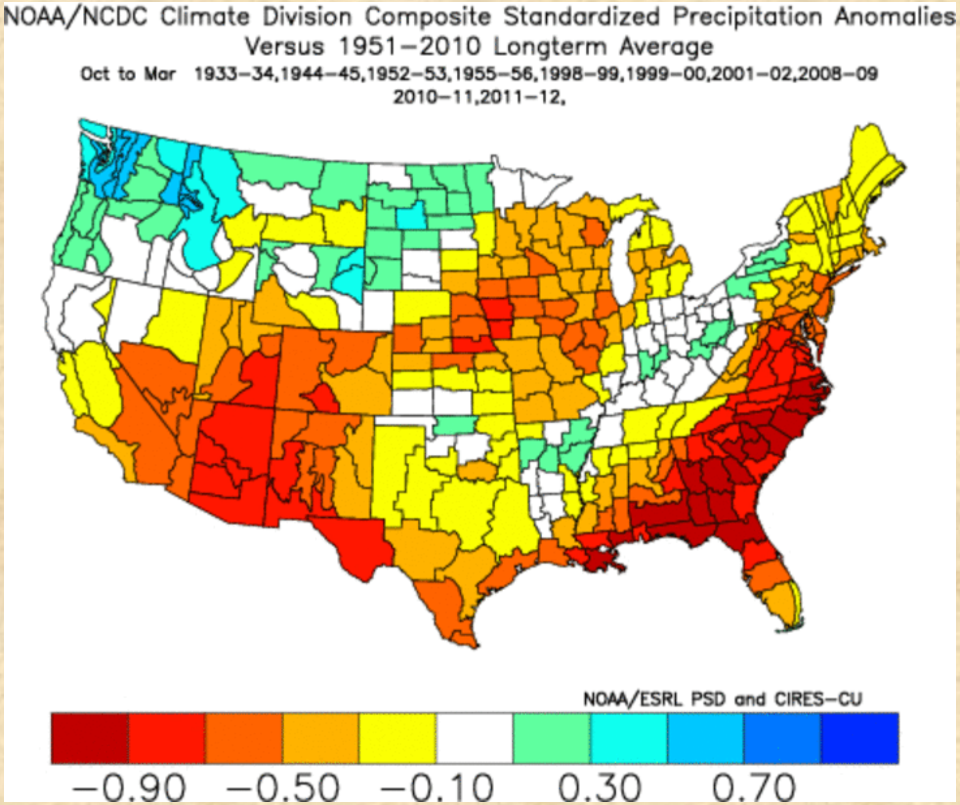
Other important interannual climate drivers

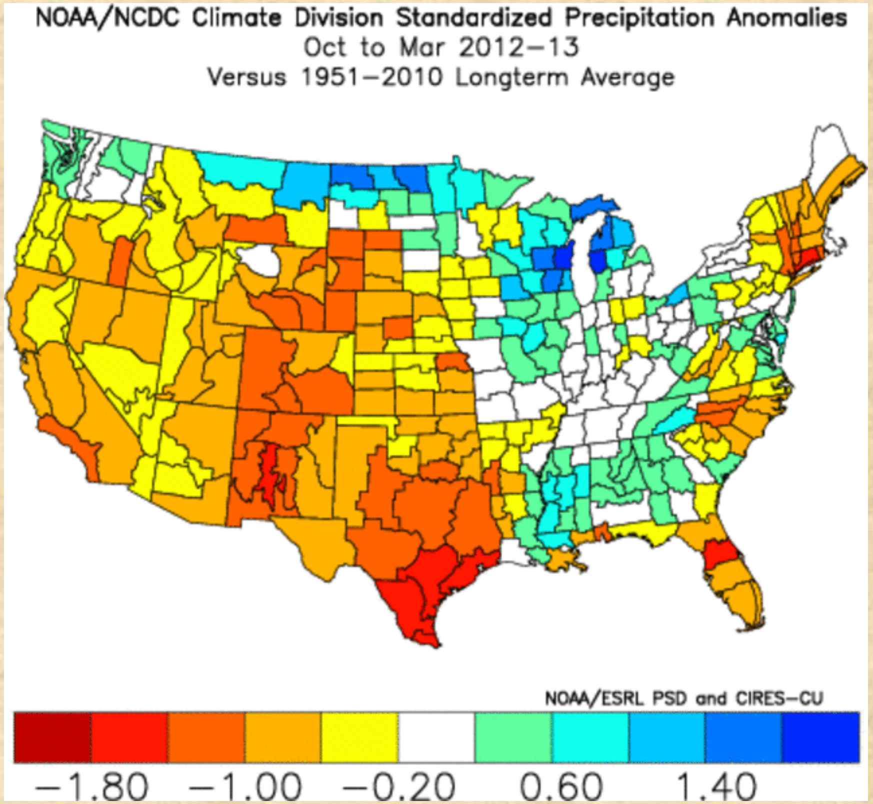


Pacific versus Atlantic

In five different General Circulation Models, a cold Pacific combines with a warm North Atlantic to produce most pervasive drought conditions in continental U.S.

Case in point: 2012-13



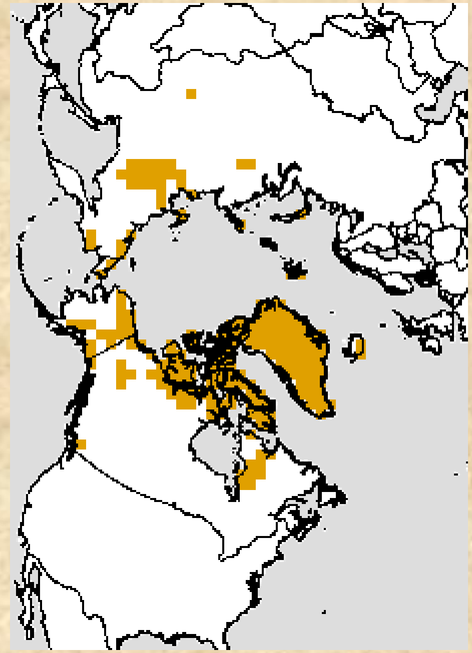


The 10 cases picked in the composite (left) were based on the lowest decile of a century of a PDO minus AMO index, since 2012 was the lowest index value on record for June-September '12. I would call this a 'forecast of opportunity'...

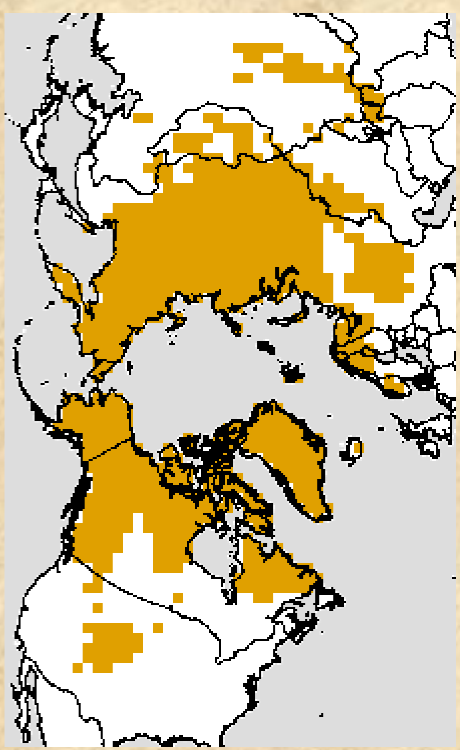
Winter half-year of 2012-13 ended up mostly dry (right), particularly in the southern high plains. This was reasonably well anticipated by my PDO-AMO composites, while ENSO stayed neutral, thus giving little guidance from that end.

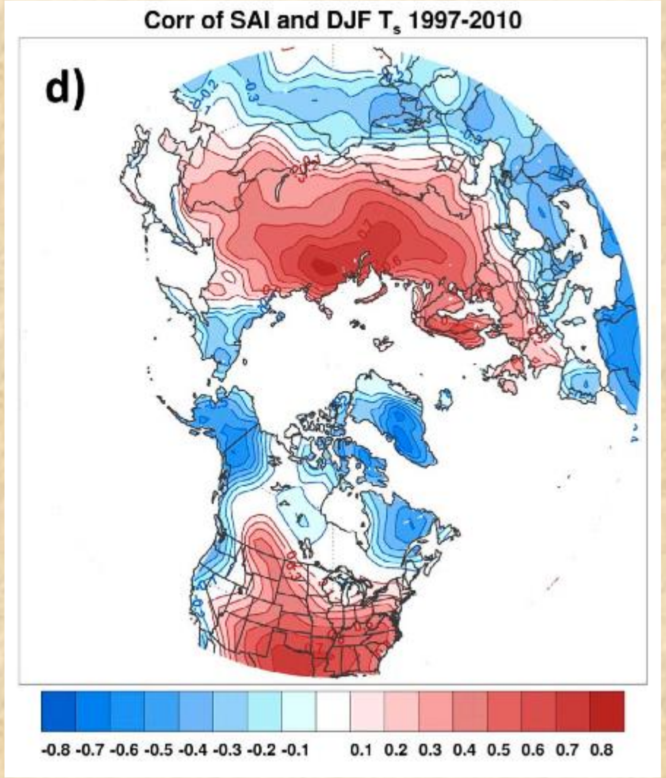
October Snow cover: Evolution in 2009 towards negative AO

30 Sep'09



31Oct'09

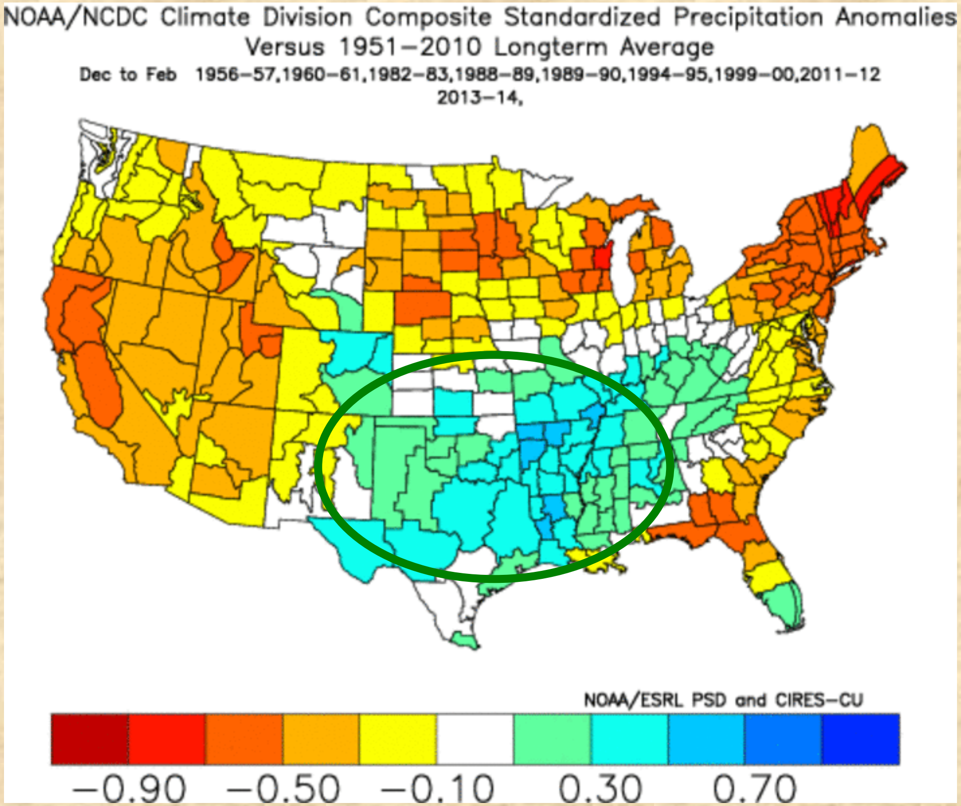


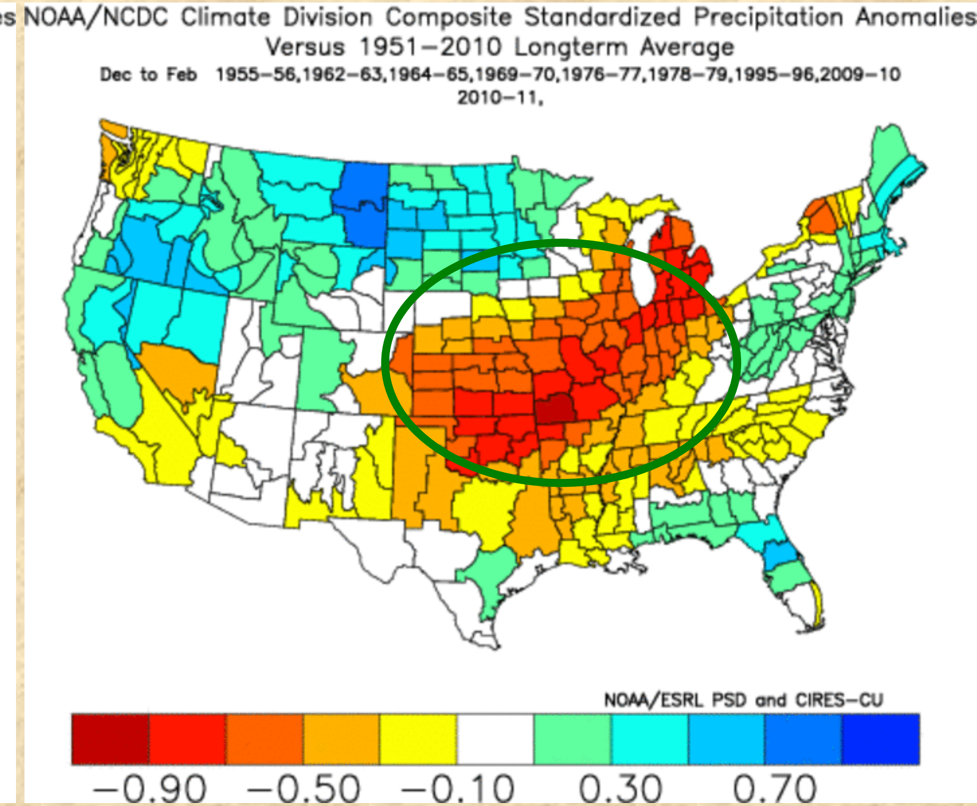


Eurasian Snowcover: 30 Sep'09(top left), and 31 Oct'09 (middle): an increase from below normal to well-above normal, especially south of 60° N! Judah Cohen's snowcover-AO hypothesis (e.g., Cohen and Jones, 2011; right) was borne out, as the following winter had the lowest AO values on record, although it was not quite as cold as in earlier negative AO winters.

Data: http://climate.rutgers.edu/snowcover/

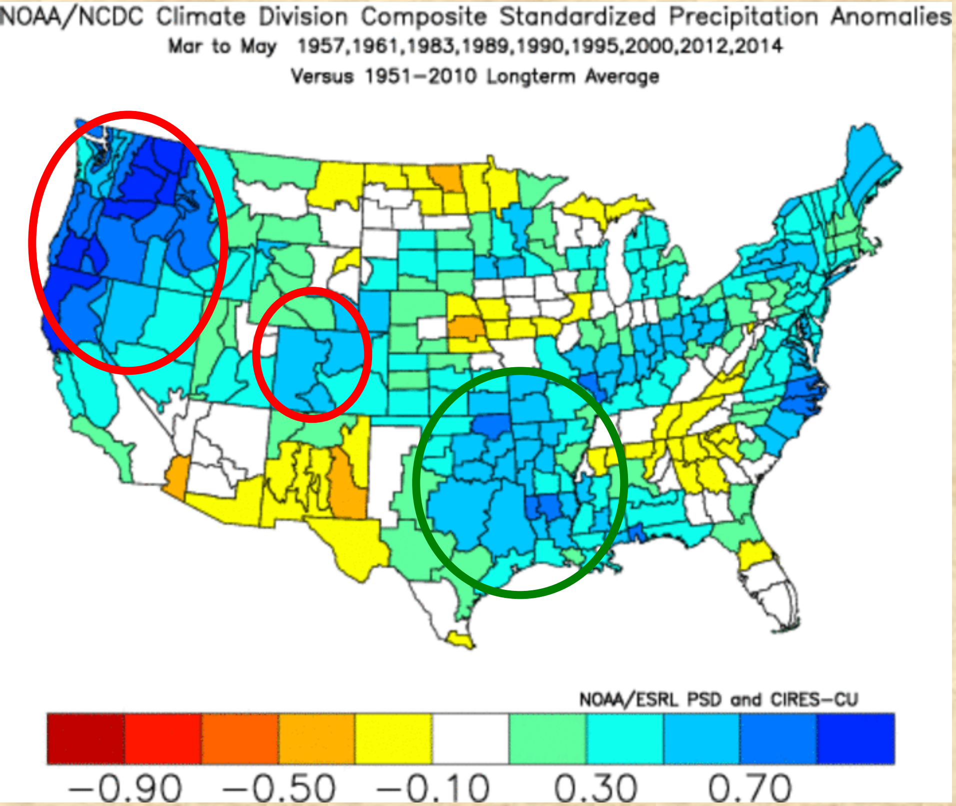
NAO+ (left) vs. NAO- (right) during winter

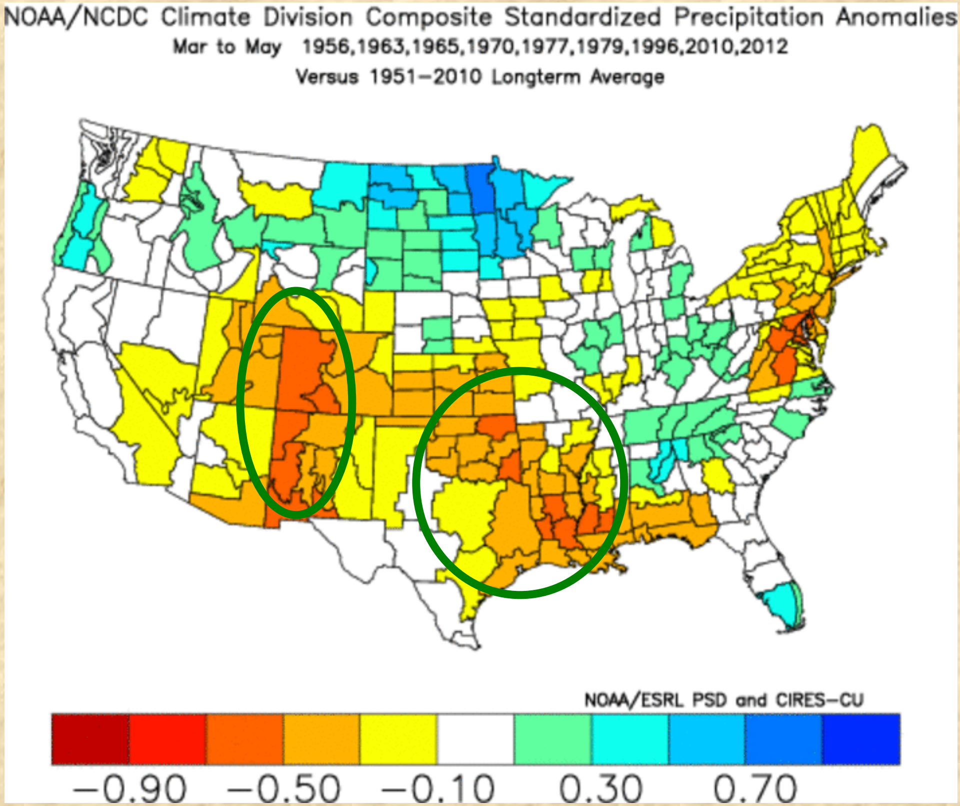




The (N)AO also redistributes precipitation over North America – during winter, positive cases (left) are often wet in the south-central U.S. (including 2011-12 when it mitigated the great Texas drought of 2011), but dry in CA (as in 2011-12 and 2013-14). Negative cases (right), sometimes associated with low sea ice in preceding summer (2009 and 2010), show very dry conditions in central U.S., last seen in 2010-11.

Winter NAO+ (left) vs. NAO- (right) foreshadows spring





Some of this signal carries over into spring, positive cases (left) often continued wet in the south-central U.S., but also further to the west coast. Negative cases (right) show dry conditions from southwestern U.S. to the Gulf Coast, again, AFTER winter NAO conditions.

Concluding Remarks

- **Climate Prediction Center (CPC) has achieved mixed success in combining long-term trends with ENSO footprint to make seasonal forecasts in this country. This is currently being augmented by incorporating coupled model guidance which has seen its best success for monthly forecasts associated with tropical intra-seasonal oscillations (March 2012).**

- **'Optimum Climate Normals' (trends) have not worked out as well as expected in recent years, in part due to the 'warming hiatus'. The lack of strong El Niño events since the late 1990s has not helped forecast skill either.**

- **Long-term trends of extreme weather events are also not as convincing as some had thought after IPCC 4, perhaps because its half-century analyses were compromised by PDO and AMO, while more recent analyses got into century scales where more than one cycle of these multi-decadal phenomena got sampled. This does not exclude the possibility that more clear-cut trends will emerge in coming decades.**

Concluding Remarks & Omissions

- **While waiting for coupled models to become more and more realistic, statistical tools are still one way to exploit 'natural' climate variability to benefit seasonal forecasts. This has already helped in extending the forecast horizon during long-lived La Niña events, in exploiting extreme phases of the PDO and AMO, and in anticipating the winter phase of the Arctic/North Atlantic Oscillation.**

- **We have only scratched the surface on other weather-climate features such as 'Atmospheric Rivers', so critical for CA precipitation, land surface memory due to soil moisture and/or snow cover, and the connection between sea ice loss and general circulation changes.**

- **From a local agricultural stakeholder perspective, a more sophisticated approach is needed than waiting for forecast skill to become perfect *(good luck with that*). In Australia (where agricultural subsidies are minimal compared to the U.S.), folks are advised to plant hardier crops when El Niño-associated droughts are more likely, while planting higher-risk, but also higher-return crops during La Niña. Also: location, location, location! <'11: CO hay helped TX with high profits>**